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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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TURTLEBACK FAULTS OF DEATH VALLEY, CALIFORNIA: A REINTERPRETATION

BY HARALD DREWES

ABSTRACT

Turtlebacks are smooth, curved surfaces, which form north-northwestward-plunging elongate domes on the east side of Death Valley. These surfaces are roughly parallel to bedding or foliation of anticlines in Precambrian schist, gneiss, and marble. Late Cenozoic fan and playa deposits are faulted over these surfaces along the turtleback faults.

Previously the turtleback faults have been interpreted as part of a thrust fault, perhaps the Amargosa thrust fault, that was arched after thrusting. They are interpreted here as individual normal faults younger than the thrust fault and, contrary to previous interpretations, much younger than the formation of the anticlines in the Precambrian rocks.

The tectonic history of this unusual area is here considered to include the following events: (1) Precambrian folding of the Precambrian rocks; (2) post-Paleozoic and pre-middle(?) Tertiary Amargosa thrusting; (3) uplift and erosion of Paleozoic strata and the Amargosa thrust fault, down to the folded Precambrian rocks in the Black Mountains block; (4) Middle(?) Tertiary rhyolite extrusions and the accumulation of later Tertiary fan and playa deposits; (5) Pliocene or Pleistocene uplift of the Black Mountains relative to Death Valley, along the Black Mountains fault system, with consequent removal of support for the Tertiary deposits on the turtleback surfaces, and the development of the turtleback faults by normal faulting, or sliding, of the Tertiary sedimentary rocks down the turtleback surfaces toward Death Valley; and, (6) Pleistocene to Recent renewal of movement on the Black Mountains fault system.

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INTRODUCTION AND ACKNOWLEDGMENTS

Turtlebacks are extensive, smooth, curved topographic surfaces that resemble the noses of large, elongate domes or the carapaces of turtles. They were first mapped, described, and named by Curry (1938, p. 1875; 1954, p. 53–59) and apparently are unique to the Death Valley area. The surfaces are exposed over many square miles. Their over-all smoothness is impressive, although in detail they are incised by gulleys and small canyons. The surfaces are only slightly dissected at lower altitudes and are progressively more dissected at higher altitudes. On the highest parts, 2000–4000 feet above the base, the degree of dissection of the turtlebacks is comparable to that of the adjacent slopes, and the identity of the surfaces is lost. The amplitude of the curvature of these elongate domes is of the order of a few thousand feet. Their axes are parallel and plunge gently north-northwest-

ward toward the Death Valley structural depression. The turtleback surfaces are underlain by folded metamorphic rocks and are overlain by Cenozoic sedimentary and volcanic rocks that are systematically deformed around the turtlebacks. The turtleback surfaces are followed by fault surfaces that separate the Cenozoic rocks from the Precambrian rocks.

The turtleback faults may be exhumed parts of an overthrust fault that was once planar but has been folded (Curry, 1954, p. 53–59), or they may be exhumed parts of several normal faults. The similarity between the turtleback surfaces and the folded Amargosa thrust fault in a nearby area and the possibility that one of the turtlebacks is the same surface as that on which the Amargosa thrust fault moved apparently suggest to Curry (1954, p. 59) that they are remnants of one structural surface.

I suggest that the turtleback faults are normal faults younger than the Amargosa thrust fault. By this hypothesis the turtleback surfaces are not surfaces that were folded after movement on the turtleback faults but are the exhumed surfaces of resistant layers in folds of Precambrian age. These surfaces first were the sites of deposition of Cenozoic gravel and later were separation surfaces down which these gravels slid, probably by normal faulting but possibly by landsliding. The movement on the turtleback faults and the deposition of the gravel probably are associated with the major Pliocene and Pleistocene deformation that produced the Death Valley depression.

The suggestions and stimulating discussions of some of the problems in the area by James Gilluly, C. B. Hunt, L. F. Noble, L. A. Wright, B. W. Troxel, and J. F. McAllister are gratefully acknowledged. The assistance in the field given by H. J. Moore, D. V. Lewis, and Henry Dyer, and the friendly co-operation of Fred Binnewies, Superintendent of Death Valley National Monument, and the park rangers and naturalists are also gratefully acknowledged. C. R. Longwell, M. L. Hill, L. A. Wright, G. D. Robinson, W. B. Myers, and W. B. Hamilton kindly reviewed the manuscript and made many helpful suggestions.

Geology Near the Turtleback Faults

General Geology

The Black Mountains on the east side of Death Valley consist of Precambrian metamorphic and sedimentary rocks, Tertiary(?) intrusive rocks, patches of Paleozoic sedimentary rocks, Tertiary volcanic and sedimentary rocks, and Quaternary playa deposits and fanglomerate (Fig. 1). The most striking stratigraphic feature of the Black Mountains is the absence of most of the thick section of Paleozoic rocks that is present in adjacent areas. The rocks of the Black Mountains are cut by the Amargosa thrust fault of Mesozoic or early Tertiary age, by the Black Mountains fault system of Tertiary to Quaternary age, by the turtleback faults of late Tertiary or Quaternary age, and by many other faults related to these major ones.

The Precambrian rocks consist of an older group of schist, gneiss, and marble, cut by a large body of metadiorite, and of a younger group of clastic rocks and carbonate rocks, cut by diabase sills. The schist, gneiss, and marble underlie the turtleback surfaces, and the metadiorite underlies much of the adjacent areas. The younger Precambrian rocks, the Pahrump series, underlie much of the southern end of the Black Mountains and probably lie wholly south of the Mormon Point area. The contact between the metadiorite and the schist, gneiss, and marble is commonly gradational over a broad zone, but locally it is faulted or the gradational zone is narrow, and the metadiorite appears to intrude the other rocks. The younger Precambrian rocks lie in fault contact over the older Precambrian rocks near the turtleback area, but in some places they lie unconformably over the older rocks.

Paleozoic rocks form large blocks and groups of blocks of dolomite, limestone, quartzite, and shale. The rocks in these blocks represent parts of many formations, which, together, are about 20,000 feet thick in areas adjacent to the turtleback area. In the Virgin Spring area just south of the turtleback area the blocks also include some younger Precambrian rocks that have not been distinguished from the Paleozoic rocks in Figure 1. The blocks are thrust over the Precambrian and Tertiary(?) crystalline rocks along the Amargosa thrust fault. Noble (1941) has described in detail the relations of the blocks to each other and to the thrust fault in the Virgin Spring area. The thrust fault beneath the Paleozoic rocks and the unconformity above them lie close to the present topographic surface over a large area.

Tertiary(?) rocks are monzonites that intrude the older Precambrian rocks. Contacts are commonly gradational over a broad zone

FIGURE 1.—INDEX MAP AND GENERALIZED GEOLOGIC MAP OF THE AREA OF THE TURTLEBACK FAULTS
Late data indicate that the monzonitic rocks are Tertiary (?) rather then Mesozoic (?).
The geology south of 36°00' is adapted from Noble and Wright (1954, Pl. 7).

Lead-alpha age determinations of zircon from these rocks give ages of 45±10 m. y. and 30± 10 m. y. (T. W. Stern, written communication).

Most of the Cenozoic rocks are older Tertiary rhyolite flows and pyroclastic rocks that contain some intercalated sediments and associated intrusive felsite bodies; they also include younger Tertiary and Quaternary playa deposits, fanglomerate, basalt flows, and gravel. The older Tertiary volcanic rocks unconformably overlie the older rocks. Many of the older Tertiary sedimentary and intrusive rocks contain fragments of the monzonite and older rocks. The sedimentary rocks contain no fossils. The younger Tertiary and Quaternary rocks lie unconformably on the older rocks. The red fanglomerate and the playa deposits in the Copper Canyon area are the oldest of the younger Tertiary and Quaternary deposits and contain abundant fragments of the rhyolite volcanic rocks. The playa deposits in the Copper Canyon area contain bird and mammal tracks that suggest a Pliocene age (Curry, 1941, p. 1979). Gray fanglomerate, probably correlative with the Funeral fanglomerate of Pliocene(?) age, lies with minor unconformity over the red fanglomerate in the Copper Canyon area and occurs near Mormon Point and in scattered patches throughout the Black Mountains. The youngest fanglomerate at Mormon Point is unconformably overlain by beach gravels associated with Lake Manly, which is probably of late(?) Pleistocene age.

The main structural features in the turtleback area include the Amargosa thrust fault, the Black Mountains fault system, and the turtleback faults. The Amargosa thrust fault is mapped in the Virgin Spring area, where it underlies the chaotic blocks. The direction of movement on the thrust fault is believed to have been westward and the amount of movement large (Noble, 1941, p. 980). The thrust fault is older than the older Tertiary rhyolite volcanic rocks, for the volcanic rocks intrude or lie unconformably across the fault surface, but it is younger than the Tertiary(?) monzonite, for blocks of unaltered carbonate are faulted over coarsely crystalline monzonite.

A system of faults along the western flank of the Black Mountains, here referred to as the Black Mountains fault system, consists of many normal faults a few hundred feet to a few miles long in echelon or feathering patterns. The general strike of the fault system is northward, but the larger individual faults strike north-northwestward, and the smaller faults strike northeastward. The block west of the fault system has dropped many thousands of feet; it may also have some strike-slip displacement. Several stages of movement are recorded by different amounts of displacement of the various fanglomerate and gravel bodies along the fault system. The earliest movement, younger than rhyolite volcanic rocks and older than the red fanglomerates, was perhaps Miocene or early Pliocene; the latest movement, younger than all but the youngest gravel, was Recent. The details of the movements, other than those details needed to explain the origin of the turtleback faults, are described and supported in another paper on the geology of the Funeral Peak quadrangle, now in manuscript form.

The turtleback faults are low-angle faults underlying three large patches of Cenozoic rocks along the west flank of the Black Mountains. The southern two faults, the Copper Canyon and Mormon Point turtleback faults, were mapped in the Funeral Peak and part of the Bennetts Well 15-minute quadrangles; the northern fault, the Artists Drive turtleback fault, was examined only briefly. The faults follow the turtleback surfaces, which are broadly arched and dip gently toward Death Valley. The hanging wall of the turtleback faults moved down toward Death Valley.

Structure of the Copper Canyon Area

The Copper Canyon turtleback is the surface of the prominent northwestward-plunging ridge south of Copper Canyon (Fig. 2). Curry (1954, p. 53) considers it to be the type turtleback because of its excellent exposure. Structural features pertinent to the development of the turtleback fault include the deformed footwall rocks, the deformed hanging-wall rocks, details of the fault surface itself, and the Black Mountains fault system.

The footwall block includes schist and gneiss in the southern part of the area and, faulted against them, massive metadiorite in the eastern part of the area. The foliation of the schist and gneiss almost parallels the bedding. The metasedimentary rocks are warped into a broad fold whose axis plunges 15°–30° N.-NW. The surface of the ridge south of Copper Canyon, which is the turtleback surface, is roughly parallel to the flanks of the fold.

The hanging-wall block includes red fanglomerate and playa deposits and overlying gray Funeral fanglomerate, which, together, are about 12,000 feet thick. Immediately above the fault the rocks consist of abundant

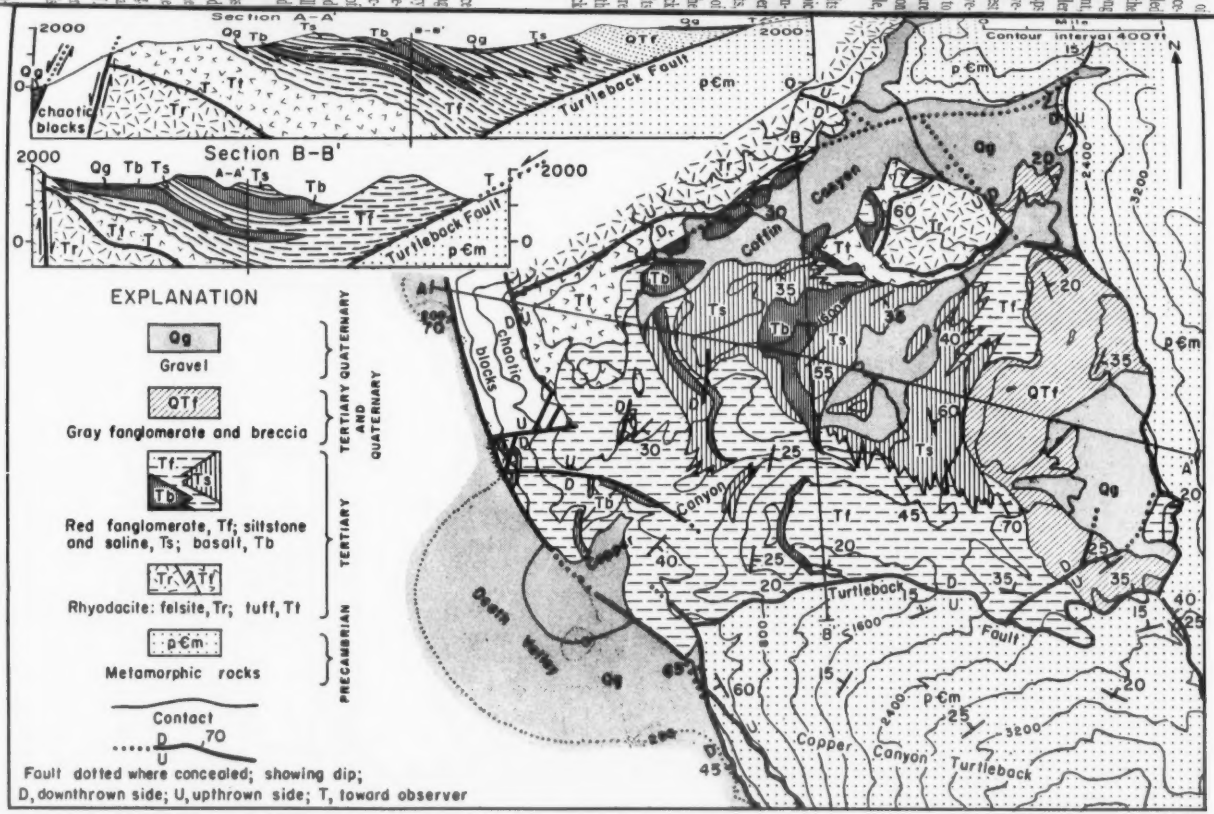

FIGURE 2.—GEOLOGIC MAP AND STRUCTURE SECTIONS OF THE AREA NEAR THE COPPER CANYON TURTLEBACK

coarse, unsorted, angular fragments with a little fine matrix. A few tens of feet to 100 feet above the fault, beds of the hanging-wall block roughly parallel the fault or dip gently in the opposite direction. Farther above the fault, bedding is more distinct; dips range from 30° to 70° toward the fault, and the strikes of the beds do not parallel the strike of the fault.

The rocks of the hanging-wall block also are slightly deformed by a fold and by faults. The rocks are warped into a broad southeastward-plunging syncline, along the axis of which the dips are, anomalously, steeper than on the limbs. The thickest section of sedimentary rocks lies along the synclinal axis. A few normal faults of large displacement and many unmapped faults of small displacement cut the hanging-wall rocks. Most of them strike northeastward, and their northwest sides are displaced relatively downward. The large normal fault in the southeast corner of the Copper Canyon area is confined to the hanging wall. In the same area gray fanglomerate of the hanging wall is repeatedly faulted against an underlying thick gouge sheet that follows the turtleback fault. The faults between the fanglomerate and the gouge sheet strike northeastward and dip steeply northwestward; their displacement is small, and they end within the gouge sheet.

The Copper Canyon turtleback fault is almost continuously exposed along the south side of the Copper Canyon area (Pl. 1, figs. 1, 2) and is well exposed locally along the east side (Pl. 2, fig. 1). Within the Copper Canyon area dips on the fault are gentle, but just north of it along upper Coffin Canyon they are steep. The fault is marked by one or two sheets of reddish gouge, generally a few inches to a few feet thick but as much as 30 feet thick. The gouge consists of unsorted, angular fragments of the adjacent rocks that are as large as boulders but commonly are the size of pebbles, set in a compact matrix of finer fragmental material (Pl. 2, fig. 2). Abundant slickensides that trend east-west lie on the fault plane near its southwest end.

In the Copper Canyon area a large fault trending north-northwestward, part of the Black Mountains fault system, truncates both hanging-wall and footwall rocks of the turtleback fault and dips 45°–70° W. The gouge and shear zone along this fault is thick at the foot of the mountains between the fan deposits. It is unclear whether the turtleback fault and the north-northwest-trending fault merge or whether one truncates the other, because exposures are poor where they meet. The foliation in the rocks that form the footwall block of both faults probably localized shear planes of both faults, so that reliable age relationships between the faults would not be obtained even if the exposure were better. The latest movement on the Black Mountains fault system in this area is younger than the latest movement on the turtleback fault, for the scarp in the red fanglomerate at the mouth of Copper Canyon is a slightly modified fault scarp, whereas the scarp in the same rocks at the turtleback fault has been eroded back many hundreds or even thousands of feet across the turtleback surface, judging from the extent and degree of preservation of the surface, and the scattered outliers on one turtleback.

Structure of the Mormon Point Area

The Mormon Point turtleback is the surface of the northwestward-plunging, prominent spur descending from the flank of Smith Mountain (Fig. 1) to Mormon Point in the western part of the Mormon Point area (Fig. 3). A profile of this turtleback is shown by Wright and Troxel (1954, Fig. 14). The general structure of the Mormon Point area is similar to that in the Copper Canyon area, but a few details differ: some of the rocks of the footwall block are tightly folded, and the rocks of the hanging-wall block are less varied and are younger than most of those in the Copper Canyon area; the Mormon Point area is bounded on the north by small northeast-trending faults and on the northeast and southwest by large north-northwest-trending faults, all of the Black Mountains fault system.

In the western part of the area the footwall block consists of marble and schist, and in the eastern part it consists of massive metadiorite. Near the turtleback fault gradation of the metadiorite into the schist over a few tens of feet suggests an intrusive contact. The rocks of the footwall block below the turtleback surface are folded into a northwestward-plunging anticline roughly parallel to the turtleback surface. The rocks of the footwall block about a mile east of the anticline are folded into a tight syncline whose axis parallels that of the anticline and whose east limb is nearly vertical. The schist and marble of the anticline extend up the ridge at Mormon Point to an altitude of about 3000 feet, where they plunge into a cliff and are either capped or truncated by metadiorite. Monzonitic rocks underlie the

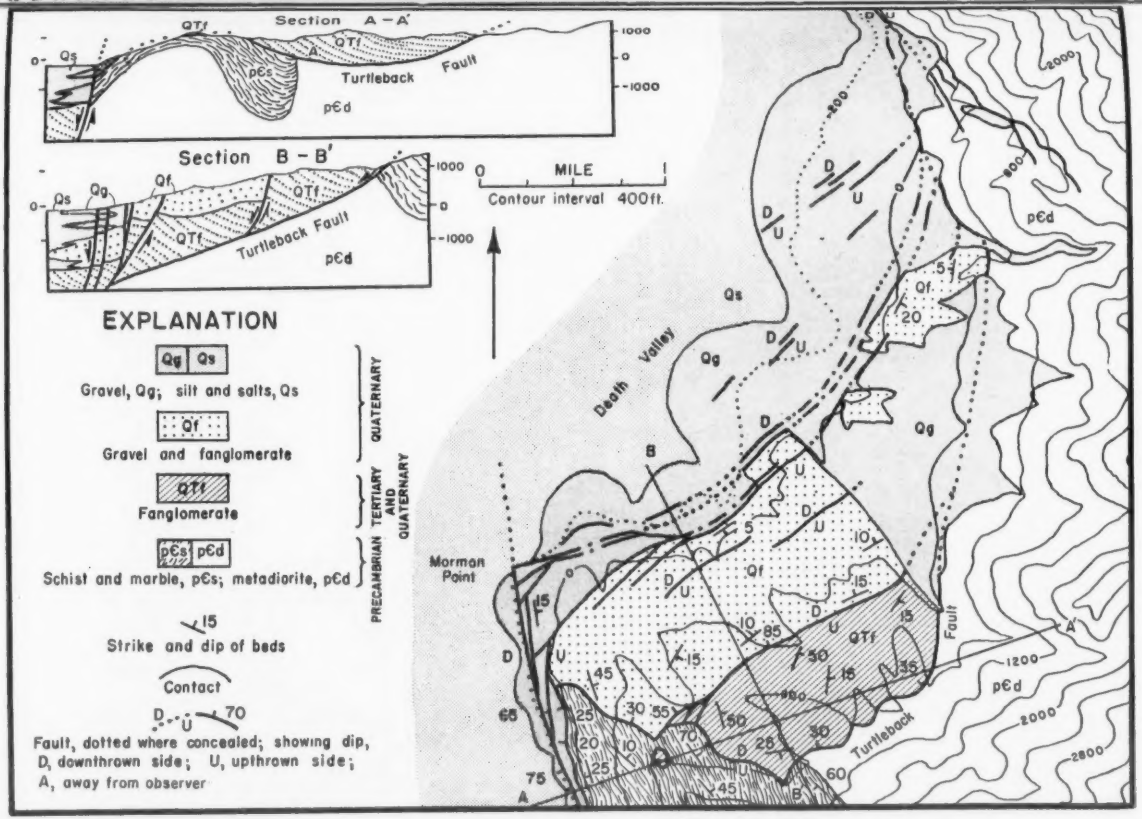

FIGURE 3.—GEOLOGIC MAP AND STRUCTURE SECTIONS OF THE AREA NEAR THE MORMON POINT TURTLEBACK

high peaks and ridges on Smith Mountain (Fig. 1).

The hanging wall consists of gray fanglomerates and gravel. The oldest fanglomerate is well consolidated and gently tilted and is correlated with the Funeral fanglomerate. The younger fanglomerates are less well consolidated and less deformed than the adjacent Funeral fanglomerate. The surface of the youngest fanglomerate contains cut terraces and is unconformably overlain by beach gravels of late(?) Pleistocene Lake Manly. The rocks resting on the footwall grade upward from fault gouge, through sedimentary breccia, into fanglomerate, as they do in the Copper Canyon area.

Several northeast-trending, steep normal faults cut the hanging-wall rocks into blocks that are tilted southeastward and displaced downward to the northwest. Faults that have similar trend and displacement direction and possibly similar dip cut all but the youngest fan gravels overlying the rocks of the hanging wall. The large fault on the northwest side of the block of Funeral fanglomerate splits into three parts near its junction with the turtleback fault; the dips of the three parts flatten, and they merge with the turtleback fault. The blocks are tilted at different angles toward the turtleback fault; the southeasternmost block, which has the oldest rocks, dips 15°–50° SE., and the northwesternmost block, which has the youngest rocks, dips 3°–10° SE. Locally the beds within the blocks dip erratically.

The Mormon Point turtleback fault is moderately well exposed around the base of the turtleback and around the embayment east of the ridge. Dips along the trace of the fault are about 30°. A gouge sheet occurring along the fault is similar to that along the Copper Canyon turtleback fault.

Faults that trend north-northwest and that trend northeast, all within the Black Mountains fault system, bound three sides of the Mormon Point area. Two large faults and many unmapped small faults on the southwest side of Mormon Point dip 45°–70° SW. The large fault on the northeast side of the Mormon Point area splits into many smaller faults that diverge and gradually disappear southward, either because they die out in the crystalline rocks or because they are covered by gravel younger than the faulting. The faults of the northeast-trending group of the Black Mountains fault system parallel the faults in the hanging-wall block of the turtleback fault and are distinguished from them by a recent displacement of 100-200 feet, comparable to the recent displacement all along the Black Mountains fault system in the turtleback area.

The inferred age relationship between the turtleback fault and the Black Mountains fault system is the same at Mormon Point as near Copper Canyon: the Black Mountains fault system was active after the turtleback fault. The southwest end of the turtleback fault merges with the eastern fault of the north-northwest-trending group of the Black Mountains fault system. Where they merge the dips of the eastern fault and the turtleback fault flatten to about 20°. Some movement on these two faults may have been synchronous. The latest movement on the Black Mountains fault system, however, is along the western fault, rather than the eastern one, and is younger than the latest movement on the turtleback fault, for the scarp along the western fault is a young fault scarp, whereas the scarp along the turtleback fault has been eroded back at least many hundreds of feet across the turtleback surface.

Present Interpretation of the Turtleback Faults

New interpretations that are based on new observations are: (1) the Copper Canyon and Mormon Point turtleback faults are not continuous with the Amargosa thrust fault, (2) they are several normal faults rather than one

Plate 1.—COPPER CANYON TURTLEBACK

Figure 1.—The Copper Canyon turtleback as seen from the west. Unit pЄm, metasedimentary rocks, is the footwall, and unit Tf, red fanglomerate, is the hanging wall of the turtleback fault, which follows the broken line.

Figure 2.—The Copper Canyon turtleback area as seen from the north. Unit pЄm, metasedimentary rocks, is the footwall of the turtleback fault; units Tf, red fanglomerate, Ts, siltstone and salines, and QTf, gray fanglomerate and breccia, are the hanging wall of the turtleback fault. The turtleback surface lies below and to the right of the symbol pЄm. The trace of the axis of the plunging syncline in the rocks of the hanging wall lies between symbol QTf and the lower right corner of the photograph.

FIGURE 1

FIGURE 2

COPPER CANYON TURTLEBACK

FIGURE 1

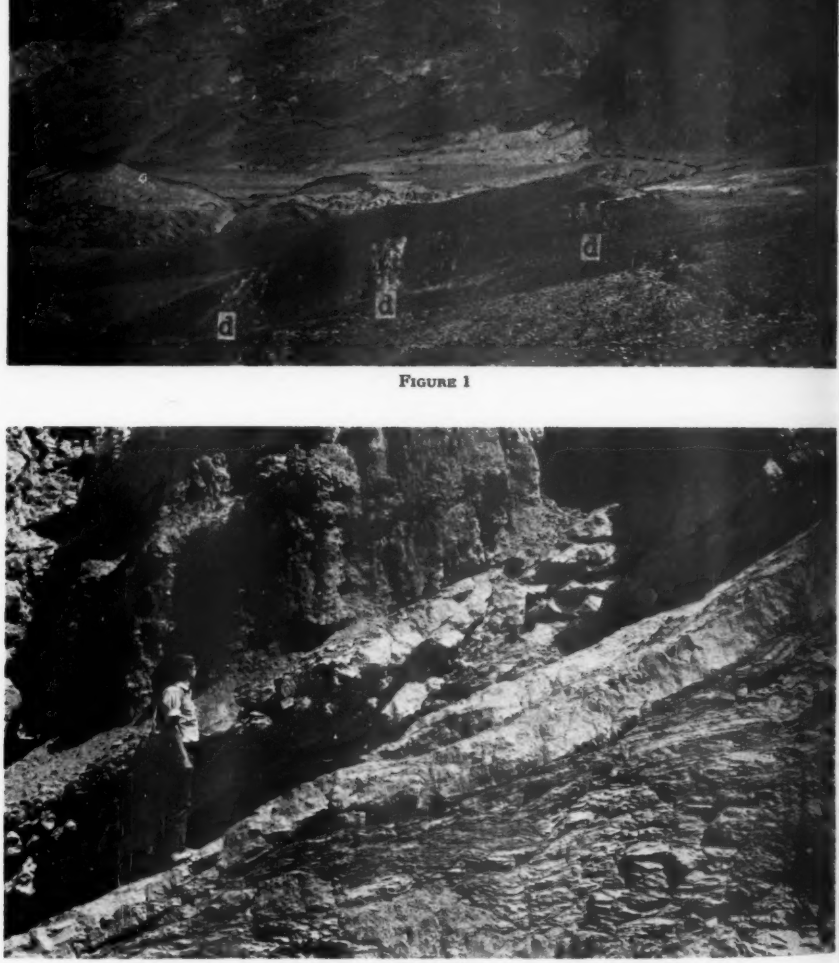

FIGURE 2

COPPER CANYON TURTLEBACK FAULT

thrust fault, and (3) the turtleback surfaces were folded in Precambrian time and before the movement on the turtleback faults, rather than in Tertiary time and after the movement on the turtleback faults. The new interpretations lead to an alternate hypothesis of the origin of the turtleback faults: one of several periods of large-scale normal faulting along the eastern edge of Death Valley removed the support of block of fanglomerate in the Black Mountains and let them slip toward Death Valley; further faulting along the eastern edge of Death Valley has truncated the blocks of fanglomerate, and younger sedimentary rocks cover those parts of the blocks that slid into Death Valley.

The turtleback faults are not continuous with the Amargosa thrust fault. The movement on the Mormon Point turtleback fault is younger than that on the thrust fault, and the turtleback surface appears to be structurally lower than the plane of the thrust fault. The movement on the turtleback faults is clearly younger than that on the thrust fault, for the rhyolite volcanic rocks that lie unconformably on the chaotic blocks associated with the thrust fault are the chief source of the oldest rocks in the hanging-wall block of the turtleback faults. The surface on schist and marble along which the hanging-wall block of the turtleback fault moved on the northwest end of the Desert Hound anticline plunges into, or is truncated by, massive metadiorite, which is intruded higher up the ridge by monzonitic rock. But the Amargosa thrust fault projects over the same rocks from the southeast end of the Desert Hound anticline. The fault surfaces are on different planes, then, unless it is assumed that they were offset by an unknown transverse structure. However, the fault surfaces may follow different bedding or foliation planes on the same doubly plunging anticline, if the anticline is older than the faults. At least two periods of erosion and one of volcanism separate the times of movement on the thrust fault and the turtleback fault. The Amargosa thrust fault may be as old as Paleozoic or as young as middle Tertiary; the turtleback faults are of Pliocene or Pleistocene age.

The evidence for normal movement or possibly landsliding on the turtlebacks faults is not so strong as the evidence suggesting that these faults were not continuations of the Amargosa thrust fault, but the evidence for normal movement or landsliding is far better than any for thrust movement. In the turtleback area no thrust faults are known other than the Amargosa thrust fault, but many periods of normal faulting occur after the movement on the thrust fault. The hanging-wall blocks of the turtleback faults moved northwestward toward Death Valley and down. The steep normal faults in the hanging-wall blocks of the turtleback faults that merge with the turtleback faults were probably formed by tension rather than compression. Possibly most of the minor faults in the hanging-wall blocks are internal adjustments to stresses set up during the movement of the blocks. The youngest rocks in the hanging-wall block of the Mormon Point turtleback fault are poorly consolidated and are no more deformed than are adjacent well-consolidated rocks of the hanging-wall block. The deformation of the hanging-wall blocks, taken as a whole, is more compatible with normal faulting, or possibly landsliding, than with thrust faulting on the turtleback faults.

Arguments used against a normal-fault origin of the turtleback fault are its large extent, the severe disturbance of the material above the fault, and the low angle of the fault (Curry, 1954, p. 57). The first argument, concerning "... their widespread occurrence and areal extent...", for they "...appear to be parts of a single great break.." (1954, p. 57, Fig. 1), is weak, because to connect the turtleback fault between the turtlebacks the high-angle faults along the west front of the Black Mountins must be interpreted as continuous with the low-angle faults on the turtlebacks, and the remaining "frontal fault" must be broken into many segments. It seems more tenable that a "frontal fault" with many thousands of feet of vertical displacement, as is the case here, forms a continuous system, and that the continuity of the turtleback faults either does not exist or has not been demon-

PLATE 2.—COPPER CANYON TURTLEBACK FAULT

FIGURE 1.—View northeast down the turtleback surface at Copper Canyon. The stripped structural surface truncates dikes, d, in the footwall rocks. Broken line follows the Copper Canyon turtleback fault.

FIGURE 2.—Copper Canyon turtleback fault. One fracture of the fault is chest high to the figure, and another is at his feet. The hanging wall is massive sedimentary breccia.

strated. The turtleback faults are each only a few miles long when considered as separate structures and are not too long for normal faults or landslides. In the second argument against a normal-fault origin for the turtleback faults Curry (1954, p. 57) mentions "... the chaotic structure, profound and apparent haphazard disorder, and intense crushing of the rocks that lie upon the surface...." However, in the Copper Canyon and Mormon Point areas the structure is orderly, and the intense crushing is restricted to a thin sheet of gouge. In the third argument "... the low angle of large areas of the surfaces..." is not considered attributable to normal faulting. Most of the turtleback faults dip 20°–30°, a slope ample for normal faults (Longwell, 1945, p. 107–118) and landslides, particularly where the foliation of the rocks of the footwall is favorably inclined, and where the rocks of the hanging wall contain silt, clay, and gypsum.

The turtleback surfaces are probably bedding and foliation surfaces that were folded during Precambrian time and were first stripped in middle or late Tertiary time, rather than surfaces of pre-middle Tertiary faults that were folded after faulting. The broad arch in the schist and marble at Mormon Point is probably contemporaneous with the tight syncline east of the arch, for the axes of the folds are parallel, and the amplitudes of the folds are similar. The tight fold is not followed by the turtleback surface or fault. The folds are probably older than the Precambrian metadiorite, for the metadiorite is very little deformed, and it truncates the schist and marble, probably by intruding it. Furthermore, tight folds are not reported from either the Pahrump series of Precambrian age or from the Paleozoic rocks in nearby areas. If the folding is accepted as earlier than the movement on the turtleback faults, then the turtleback surfaces must have been stripped first before the deposition of the gravel on them. After the movement along the turtleback faults, parts of the hanging-wall blocks were stripped again to expose the present turtleback surfaces.

The preferred hypothesis explaining the turtleback faults involves only several periods of normal faulting with large displacement and relatively smooth, structurally controlled topographic surfaces sloping toward the downthrown block. Rapid deposition of gravel accompanied and followed early downward movement of the Death Valley block and covered the stripped structural surfaces on the adjacent flank of the Black Mountains. Renewed major downward movement left the blocks of sedimentary rocks on the previously stripped surfaces poorly supported, for in the crystalline rocks the faults dip 45°–70°, whereas in the overlying gravel the faults are steeper (Fig. 4). The blocks of sedimentary rocks slipped down toward the basin and broke into smaller blocks that rotated to reverse the initial direction of dip of the gravel. In the Copper Canyon area, where the block of sedimentary rocks deposited on the stripped structural surface is thick and contains weak clay and salines, the rocks were wedged into a trough in the underlying stripped surface and were tilted more than elsewhere during the downward sliding of the block. Configuration of the fault plane and flowage of the clay and salines must account for the steep dips along the axis of the syncline in the rocks of the hanging wall of the Copper Canyon turtleback fault.

The turtleback faults appear to be low-angle normal faults rather than landslides, but a hypothesis of landsliding also has some merit. In landsliding, the trace of the surface of movement reaches the surface on all sides. This cannot be seen in the Copper Canyon or Mormon Point areas, but the trace may be hidden by younger faults or younger deposits. The turtleback fault in the northeast corner of the Copper Canyon area does not appear to follow the northern edge of the fanglomerate down Coffin Canyon toward a possible closure with the southwest end of the trace of the fault. Instead, the turtleback fault, or a branch from it, continues northward up Coffin Canyon, where it becomes a high-angle normal fault. The rocks of the hanging wall of this extension or branch of the turtleback fault are older northward; in the northeast corner of the Copper Canyon area tuff older than the red fanglomerate is faulted over metamorphic rocks and a felsite intrusive into metamorphic rocks; farther north of this corner metamorphic rocks are faulted over metamorphic rocks. The shift in stratigraphic horizon of the turtleback fault or a branch from it, and the increased dip on the fault and more compatible with a normal fault than with a landslide.

The surfaces used by the turtleback faults are unusually smooth for ordinary erosion surfaces. Landsliding or faulting, possibly even thrust faulting, could help explain the origin of the surfaces, but none explains all the problem.

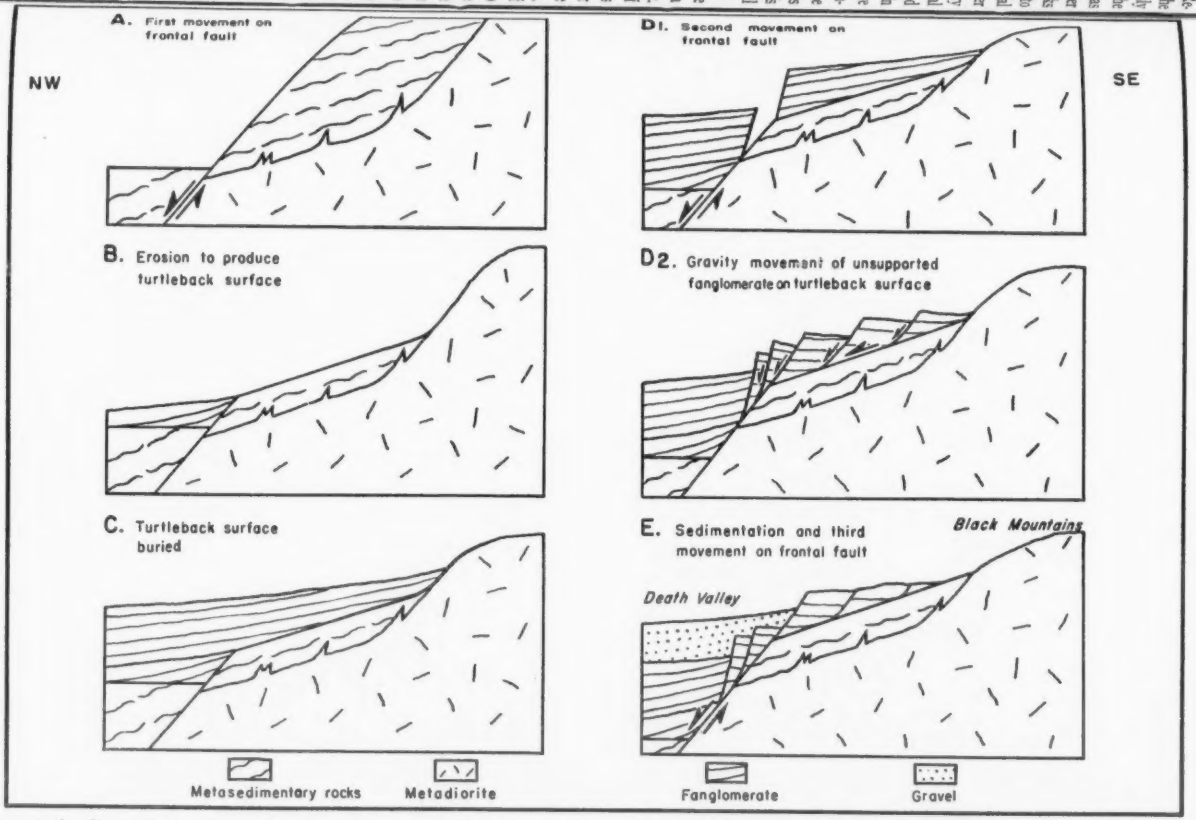

FIGURE 4.—DIAGRAMMATIC SECTIONS PARALLEL TO THE FOLDS OF THE TURTLEBACKS SHOWING THE DEVELOPMENT OF THE TURTLEBACK FAULTS
The metasedimentary rocks were folded before the faulting shown in section A. Events shown in sections D1 and D2 are simultaneous.

Moreover, the evidence for the cause of the smoothness has been removed. The smoothness of the surfaces of the turtleback faults, in contrast to the origin of the turtleback faults, therefore, remains inadequately explained.

Conclusions

The preferred interpretation of the turtleback faults is summarized in the following geologic history of the turtleback area. The foliated crystalline rocks were folded in Precambrian time and intruded by monzonitic rocks in Tertiary (?) time. The Paleozoic rocks that covered the crystalline rocks were complexly disturbed along the Amargosa thrust fault before middle(?) Tertiary time. Following considerable erosion, which removed all the upper plate of the thrust fault and much of the sheet of chaotic blocks and the thrust surface itself, rhyolite volcanic rocks were extruded and intruded in middle(?) Tertiary time. During or shortly after this time movement began on high-angle normal faults near the range front, the Black Mountains fault system. In consequence, red fanglomerate, rich in fragments of the volcanic rocks, and playa sediments were deposited in the Copper Canyon area on both sides of the fault (Fig. 4). As a result of major movement on the Black Mountains fault system in late Pliocene or early Pleistocene time, large blocks of sedimentary rocks on the flanks of the mountains moved downward along low-angle normal faults, the turtleback faults, toward Death Valley. The blocks were slightly broken, rotated, and, in the Copper Canyon area, folded. Further movements along the Black Mountains fault system offset not only the hanging-wall rocks of the turtleback faults but also offset still younger rocks. Recent gravels cover the parts of the hanging-wall blocks of the turtleback faults that slid into Death Valley.

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STRUCTURE AND PETROLOGY OF THE NORTHEAST PART OF THE SODA MOUNTAINS, SAN BERNARDINO COUNTY, CALIFORNIA

BY L. TROWBRIDGE GROSE

ABSTRACT

The geology of about 200 square miles in the northeast part of the Soda Mountains just west of Baker in the Mojave Desert of California was mapped on air photographs of scale 1:13,000.

An important N. 25° W. right-lateral fault, herein named the Soda-Avawatz fault, divides the region into two distinctly different geologic areas. In the eastern area the following rocks occur: (1) metasedimentary rocks of probable Precambrian age, (2) the Prospect Mountain quartzite which is thought to be Lower Cambrian, (3) dolomite of Middle Paleozoic(?) age, and (4) a complex of plutonic rocks ranging from diorite to granite. The western area consists of: (1) Mississippian-Pennsylvanian(?) limestone and hornfels, (2) Lower Permian limestone of the Bird Spring formation, (3) Lower Triassic limestone and shale, (4) Triassic-Jurassic andesite and quartzite herein named the Soda Mountain formation, and (5) Upper Mesozoic intrusive rocks different from those in the eastern area.

In the eastern area, Lower Cambrian(?) quartzite of restricted extent constitutes an isolated thrust complex, and intensely deformed Middle Paleozoic(?) dolomite occurs in klippen which are intruded by plutonic rocks. In the western area, highly disordered allochthonous Upper Paleozoic limestones occur in fragmentary blocks. These are irregularly downfaulted into an equally disordered para-autochthon of Mesozoic volcanic rocks. The thrust complex was passively intruded by Upper Mesozoic quartz diorite, quartz monzonite, and granite. The intrusions effected unusually large zones of contact metamorphism (garnetization) and regional hydrothermal alteration (albitization and epidotization).

Several thousand feet of the lower Pliocene Avawatz formation consisting of fanglomerate, sandstone, and monolithologic limestone breccia occurs in the district and is prevalent along the Soda-Avawatz fault zone. The limestone breccia originated by landsliding and normal fanglomerate accumulation coeval with oblique-slip movement of the Soda-Avawatz fault.

Deformation took place during the Middle and Late Mesozoic and is considered part of the Nevadan-Laramide orogeny. This resulted in isoclinal folding, thrusting, and block faulting. The upper plates of the thrusts may have moved westward with respect to the lower blocks, but the evidence is inconclusive. Granitic intrusion followed deformation and was locally guided by pre-established vertical and low-angle faults.

The Soda-Avawatz fault zone is the most prominent structure in the Soda Mountains. Ranging in width from 1 to 2 miles, it consists of three principal through-going faults and numerous branching faults characterized by wide zones of granulation and rock slivering, near-horizontal slickensides, and apparent reversal of throw along the strike. A large anticline is squeezed up within the fault zone. Most of the movement occurred during Late Cenozoic, but features indicating recent displacement are lacking. The strongest evidence for right-lateral displacement is the echelon arrangement of folds and secondary faults. Since specific geologic features in the Soda Mountains cannot be matched across the fault, the amount of displacement is unknown.

The Soda-Avawatz fault continues northward along the east side of the Avawatz Mountains and becomes the Death Valley fault zone. Together they form a regionally significant northwest-trending right-lateral fault zone. More recent movement on the east-west Garlock fault has forced an eastward bulge in the Death Valley–Soda-Avawatz fault where the faults join on the northeast side of the Avawatz Mountains.

During most of the Late Paleozoic and Mesozoic eras, the Soda Mountains area lay in a transition zone between miogeosynclinal environment to the east and eugeosynclinal environment to the west. The Death Valley–Soda-Avawatz fault seems to coincide in part with this transition zone and was perhaps localized by it.

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INTRODUCTION

Geographical Setting

The Soda Mountains are in the Mojave Desert immediately west of Baker, a small settlement on U.S. Highway 91, between Barstow, California and Las Vegas, Nevada (Fig. 1). The northeast part of the mountains is partly accessible by an unimproved road leading northward to the Blue Bell Mine area from Highway 91 and by a graded road leading westward from Silver Lake along a transmission line in the northern part of the area (Pl. 1). A jeep trail extends from Baker 4½ miles west-northwestward to the Moonshine area. Silver Lake playa is usually hard and dry enough for automobile travel to Lakeshore Hill and the Quartzite Hills.

Autumn, winter, and spring are good for field work, but summer daytime temperatures usually exceed 110° and commonly reach 120°. The temperature rarely drops below freezing during the day in winter months. Precipitation averages 3 inches per year, and most of it falls

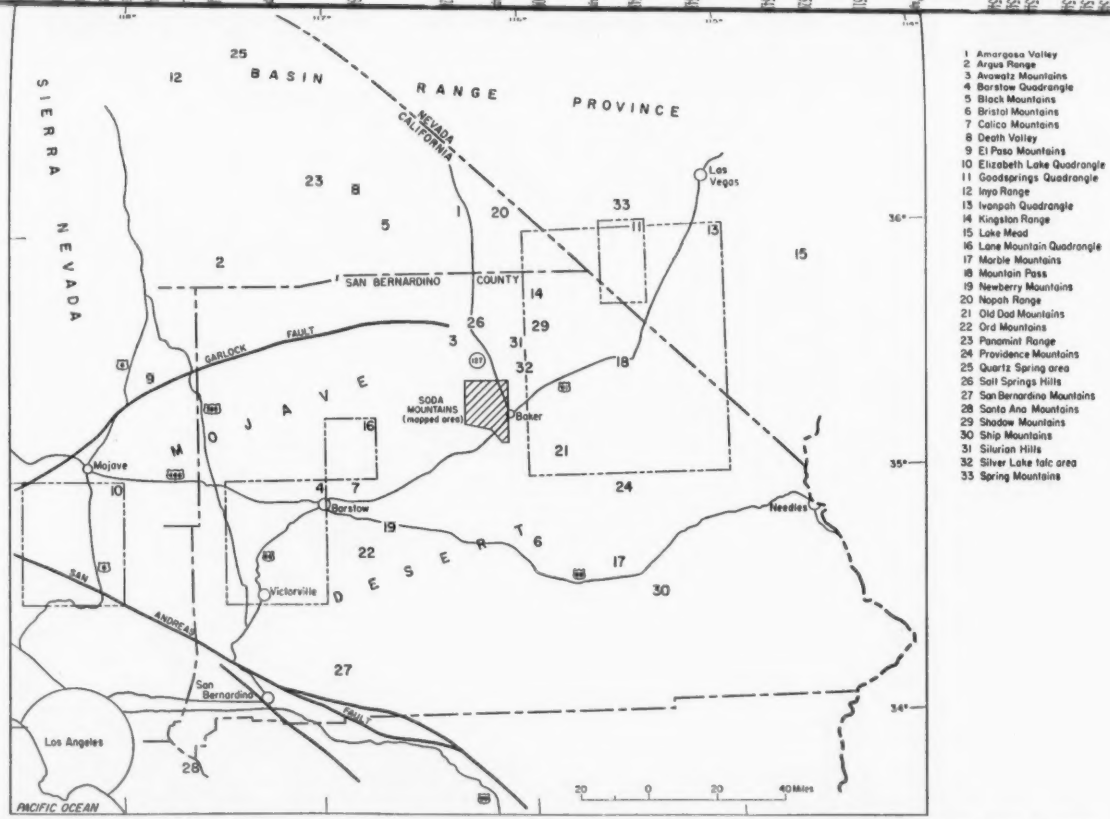

FIGURE 1.—INDEX MAP SHOWING LOCATION OF THE SODA MOUNTAINS AND OTHER GEOGRAPHIC TERMS USED IN THIS REPORT

in local summer downpours that produce flash floods. As the climate is arid and hot, vegetation is very sparse (Pl. 2). Most of the slopes are virtually bare rock, and soil is restricted to small crevices in rocks. No perennial streams or springs occur in the area; the nearest water is at Baker.

In the northeast part of the Soda Mountains elevations range from about 900 feet on Silver Lake playa and at Baker to nearly 3500 feet on Granite Ridge and Spectre Spur. The area generally rises from east to west. The line of hills from Baker to Dolomite Mountain reaches elevations of 1200–2000 feet. South Lakeshore Hill and Highway Spur rise gradually and evenly toward the prominent N. 25° W. Granite Ridge (Pl. 2). The most abrupt slopes occur on the west side of Spectre Spur (Pl. 7, fig. 1), where there is a rise of 2000 feet in a horizontal distance of 1 mile. From Spectre Spur southward is a mountainous area with highest elevations about 3000 feet and lowest about 2200 feet (Pl. 6, fig. 1).

Three large pediment surfaces, Target, Jeep, and Ruin flats, slope 2°–6° away from the mountains. That they are essentially pediments rather than alluvial fans is evident by local exposures of bedrock and inclined Tertiary strata under alluvial veneer.

Field Work and the Geologic Map

The Soda Mountains have not been mapped previously except in broadest reconnaissance (Geologic map of California, 1938) and have received only cursory mention in the literature. The area covered in this report was mapped on air photographs (1:13,000 approximately) during 6 months in 1953 and 1954. At that time there were no satisfactory topographic base maps; hence, a planimetric base was prepared (1:20,000) by the horizontal stereotriangulation (multiplex bridging) method, and the geology was carefully transferred to it. In 1957 topographic coverage became available on the Baker, Cave Mountain, Red Pass Lake, and Soda Lake quadrangles. Topographic control from these maps was then incorporated on the geologic map. Several prominent features are herein named as follows (Pl. 1): Dolomite Mountain; Baker Hill, Hopeless Hill, Quartzite Hills, Lakeshore Hill, South Lakeshore Hill, and Zzyzx Hill;[1] Highway Spur and Spectre Spur; Granite Ridge; Moonshine area; Target Flat, Ruin Flat, and Jeep Flat. An arbitrary grid system is used for reference to specific areas on the geologic map (Pl. 1), and the coordinates are inserted in parentheses in the text.

[1] Zzyzx, which may seem a misprint, is the accepted name of a small health resort on the west side of Soda Lake. It is pronounced zī'zix.

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Pre-Cenozoic Sedimentary, Metasedimentary, and Extrusive Rocks

Introduction

Ten formations of Precambrian (?), Cambrian (?), Mississippian (?), Pennsylvanian (?)

Permian, Triassic, and Jurassic (?) ages occur as fragmentary and isolated roof pendants in a large area of Upper Mesozoic plutonic rocks. Structural deformation is so severe that orderly stratigraphic succession is nowhere preserved, and only the general aspects of the stratigraphic record in the area can be deciphered.

Precambrian(?) Gneissic Complex

FIELD RELATIONS: The Precambrian (?) gneissic complex consists mainly of gneissic metamorphic rocks of great complexity and petrographic diversity. It occurs east of the Soda-Avawatz fault zone in South Lakeshore Hill, Moonshine area, and Hopeless Hill (Pl. 1). The contacts, as well as the foliation, of the gneiss generally trend northwestward. The gneiss is mostly in subvertical transitional contact with the pre-Tertiary plutonic rocks and in relatively sharp contact with the Upper Mesozoic quartz monzonite formation. No rocks are exposed directly underneath the gneiss, though on some deeper outcrops it assumes a more massive structure, which suggests downward as well as lateral transition to uniform plutonic rocks. Locally, on Hopeless Hill and South Lakeshore Hill, the gneiss is in gentle to steep fault contact with a dolomite and limestone thrust plate (N-13, P-17). The minimum thickness of the gneiss sequence is about 1700 feet as measured on South Lakeshore Hill; however, the original thickness of the section was undoubtedly much greater. Irregularities of internal structure preclude close measurement of thickness.

PETROGRAPHY: On the basis of field observation, the gneissic complex appears to consist of the following major petrographic types in order of decreasing abundance: fine-grained biotite-quartz paragneiss, biotite schist, amphibolite, quartzite, aplite, and silexite. Migmatites involving mixtures of the foregoing with granitoid rocks (which range from gabbro to granite) are widespread.

The fine-grained paragneiss, composing about two-thirds of the complex, is extensively exposed on the southern edge of South Lakeshore Hill. Most of the rock consists of fairly regular alternating quartz-rich and biotite-rich laminae an eighth of an inch to 1 inch thick. Swirled gneissic structure is locally developed. Over much of the terrain the gneissosity gives a strong impression of being inherited largely from original sedimentary lamination of an impure quartzite, and at three places sedimentary cross-bedding is preserved in relatively pure quartzite beds. Commonly interbedded with the paragneiss are small to large layers (1 inch to 100 feet in width) of fine-grained biotite-hornblende schist, massive to schistose amphibolite, and massive quartzite. These are especially well shown on the northwest side of Hopeless Hill. Where the gneissic rocks are intimately mixed with granitic rocks and plutonic dikes, the complex becomes monotonous in its heterogeneity, and it practically defies systematic description. These migmatitic portions occur here and there throughout the gneissic complex but are most widespread in the central and northwestern part of South Lakeshore Hill. The rocks in the migmatite include the various gneissic types irregularly mixed with more massive and more nearly uniform granitic rocks. Dikes and small masses of aplite and silexite seem to be integral constituents of the more migmatitic portions of the complex.

An important feature of the gneissic complex is the transitional nature of the contacts between the various metamorphic and plutonic rocks. The transition zone may range from several inches to about 300 feet in width, and it is nowhere uniform. Irregular and sporadic occurrence of the different rocks is characteristic, but on a broad scale the migmatitic portions are concentrated near the granitic bodies.

ORIGIN: On the strength of reconnaissance mapping of the gneissic terrain, several lines of evidence favor an origin by metamorphic transformation of sedimentary rocks: (1) relict sedimentary bedding is locally preserved in the paragneiss, and much of the gneiss appears to have inherited its foliation from fine laminae in impure quartzite; (2) contacts between the different rocks within the complex and between the complex and adjacent plutonic rocks are transitional and largely without structural dislocation; (3) isolated elongated patches and bands of granitic material as well as local porphyroblastic areas selectively follow zones up to 200 feet long in the gneissic rocks; (4) some of the smaller granitic bodies faintly preserve the gneissic structure with the same orientation as in the surrounding rocks.

The writer concludes that the gneissic complex was originally impure sandstone with subordinate layers of calcareous shale and possibly basic volcanic rocks. Regional metamorphism and local granitization or migmatization transformed the sediments into their present condition. Except for the relict sedimentary bedding, however, a granitized ortho-

gneiss could also have these features. The evidence and interpretation that have emerged here are somewhat similar to those used by Anderson (1937) in the White Mountains of California and Nevada, and by Misch (1949) in the north-central Cascade Mountains of Washington.

AGE AND CORRELATION: The gneissic complex is older than the Cretaceous Teutonia quartz monzonite and the basic plutonic complex, which invade and metamorphose the gneiss. The gneissic rocks described elsewhere in the region are generally assigned to the Early Precambrian. Definitely dated Paleozoic rocks nowhere show the high degree of mineralogic reconstitution and internal deformation of the Upper Precambrian rocks (Hewett, 1956, p. 18). In the southern Death Valley region and the Avawatz Mountains, schist, gneiss, and granitic rocks are overlain unconformably by "younger Precambrian" Pahrump sedimentary rocks (Hewett, 1940, p. 239–240; Noble, 1941, p. 948–949; Wright, 1952). Precambrian gneisses, schists, marbles, and granitic rocks overlain by unmetamorphosed Lower Cambrian sedimentary rocks are mentioned by Hazzard and Crickmay (1933) in the Providence, Marble, and Ship mountains and described by Gardner (1940, p. 264–265) in the Newberry and Ord mountains. However, McCulloh (1954, p. 15) points out that some of the regionally metamorphosed and migmatized sedimentary rocks in the central Mojave Desert are likely to be Paleozoic as well as Precambrian.

A large area immediately east of the Soda Mountains is underlain by plutonic rocks, which are designated as the Halloran complex by Miller (1946, p. 499) and considered by him to be Lower Precambrian on the basis of degree of metamorphism. Hewett (1956, p. 22) and Wright (1954, p. 19), who have done systematic mapping in the region, also tentatively assign an Early Precambrian age to the metamorphic rocks of Miller's Halloran complex. In all reported localities but one, the Precambrian gneisses are overlain unconformably by relatively unmetamorphosed Upper Precambrian or younger sedimentary rocks. But Kupfer (1951) writes that in the Silurian Hills, Upper Precambrian "Pahrump rocks, 11,000 feet thick, can be traced from unmetamorphosed sedimentary rocks into feldspathized, intruded, and metamorphic rocks which previous workers called Archean" or Halloran complex.

Rocks of the gneissic complex in the Soda Mountains resemble portions of the Halloran complex, whereas correlation with Pahrump lithology appears doubtful (Kupfer and Wright, 1953, personal communication). However, the gneiss on South Lakeshore Hill displays some lithologic resemblance to the Lower Cambrian (?) quartzites which are exposed several miles north in the Quartzite Hills. Possibly, then, the gneissic complex is the metamorphosed and granitized equivalent of Lower Cambrian rocks. Feldspathization of Prospect Mountain quartzite by Upper Mesozoic quartz monzonite is reported to occur on the west side of the Kingston Range (Hewett, 1954, personal communication).

The dating of the original sediments and the metamorphism and granitization which subsequently affected them remains one of the most vexing petrologic problems in the area. The present evidence weighs slightly in favor of an Early Precambrian age for the original sediments; yet the strong possibility of Early Cambrian age should not be overlooked. The original sediments are probably no younger than Cambrian. Granitization and intrusion may have occurred in Early Precambrian or Late Mesozoic, since these are the only periods of plutonic activity known in the area.

Precambrian(?) Metasedimentary Rocks

FIELD RELATIONS: A mixed assemblage of variously metamorphosed and locally intruded sandstone, shale, limestone, and dolomite is grouped into a single formation, because of an over-all deformational and petrologic heterogeneity and because of the structural position in which it occurs in the Soda Mountains. It is exposed only in isolated masses in the Quartzite Hills, and everywhere it discordantly underlies a brecciated limestone and dolomite unit. Internal deformation is widespread, and it is impossible to trace individual beds more than several score feet. The thickest section, about 1200 feet, is exposed in the southwest part of the Quartzite Hills (H-11). Undoubtedly, the original thickness was much greater.

PETROGRAPHY: Impure quartzite makes up about three-quarters of the metasedimentary formation; calc-silicate rocks, argillite, crystalline limestone, and dolomite are subordinate. The best exposures, which lie along the shore of Silver Lake playa (H-13), reveal relatively well-ordered beds of gray, medium-crystalline, schistose dolomitic limestone, brownish-gray banded argillite (Pl. 8, fig. 1), and dark-gray, impure, fine- to coarse-grained quartzite. Also

exposed is a prominent granite dike that is typical of sporadic granitic intrusions in this formation. About 1½ miles west (H, I-11), more quartzite and argillite occur with locally developed feldspathized areas similar to parts of the gneissic unit 4 miles south. On the northeast side of Quartzite Hills (F-11), a relatively disordered section of red, white, and brown quartzite interbedded with greenish calc-silicate layers is exposed for a short distance under a thrust fault. The rocks here are moderately different from those southward owing to greater deformation and higher-grade metamorphism; calc-silicate minerals replace most of the limestone and dolomite.

AGE AND CORRELATION: No fossils occur in the metasedimentary formation. Lithologic resemblance is marked between the subordinate gneissose quartzites in this unit and those in the gneissic complex. The argillites and quartzites in this unit and in the Lower Cambrian (?) beds exhibit similarities. However, the carbonate and calc-silicate beds have no correlatives in the Soda Mountains.

Some resemblance was noted by Wright (Personal communication, 1954) between these metasedimentary rocks and some of the rocks of the Upper Precambrian(?) Halloran complex in the Silver Lake talc area 6 miles to the northeast. Other possible lithologic correlatives are the Upper Precambrian Pahrump group in the Silurian Hills and the Cambrian (?) Johnnie formation in the southern Death Valley region.

Until more data are accumulated, the age and correlation of this metasedimentary formation will remain unknown. The author has hesitatingly placed it in the Late Precambrian category, because it seems most closely allied lithologically, metamorphically, and spatially with the Lower Cambrian (?); it also exhibits features similar to the Lower Precambrian (?) gneissic complex.

Lower Cambrian(?) Limestone and Dolomite

FIELD RELATIONS: The complex assemblage of rocks in the Lower Cambrian(?) limestone and dolomite occurs in two separate areas within the Quartzite Hills. In the southern part occur isolated masses of at least 500 feet of unfossiliferous limestone and dolomite which are thrust over Upper Precambrian (?) metasedimentary rocks and are intruded by pre-Tertiary plutonic rocks. Parts of the unit are brecciated because of thrusting (Pl. 8, fig. 2) and are isoclinally folded.

In the northern part of the Quartzite Hills, the formation consists of four members as follows in ascending order: quartzite, 150 feet thick; limestone, 200 feet; quartzite and dolomite, 250 feet; and dolomite, 75 feet. The above figures for stratigraphic thickness apply to the thickest exposed section of each member. They must be regarded as very imperfect since the formation is situated in an imbricate thrust zone, and the original thickness of each member is impossible to ascertain because of an undeterminable amount of tectonic accumulation and reduction of strata. The Prospect Mountain quartzite overlies this unit with apparent stratigraphic conformity.

PETROGRAPHY: In its southern occurrence this formation is composed of buff, white, and light-gray, medium-crystalline limestone and dolomite (Pl. 8, fig. 1). In the main, the rocks are thickly interbedded, although considerable sporadic and very irregular mixing of dolomitic and limy rocks occurs. In many places it is difficult to distinguish between the two, except with the hydrochloric-acid test. However, most of the buff-weathering carbonate rocks in this formation and in other formations in the Soda Mountains are dolomite or limy dolomite. Therefore, unless critical attention need be focused on the petrography of the carbonate sedimentary rocks in the area, the buff-weathering rocks can probably be regarded as dolomite (especially if they are more coarsely crystalline and serpentinized in fractures).

In the massive carbonate rock near intrusions, small crystals of forsterite and spinel occur disseminated or roughly segregated in layers, and in many highly sheared sections a greenish-yellow mineral (antigorite ?) is present. Actually, however, contact metamorphic effects along most of the granite-limestone contact are practically nil. A thin section of schistose crystalline limestone in a thrust zone (H-13) about 50 feet above intrusive granite revealed about 95 per cent calcite, 5 per cent phlogopite, and a trace of tremolite. Post-shearing crystallization has apparently healed and largely removed cataclastic texture, which may have been present as a result of thrusting.

In the northern occurrence, the two carbonate members of the formation resemble the carbonate in the southern occurrence, except that they are apparently thinner, more dolomitic, and more highly sheared and recrystallized. The quartzite members are dark, fine- to coarse-grained, and thinly interstratified with gray siliceous dolomite. Very fine-grained hornfelsic quartzite was examined in thin section. It contains 60 per cent quartz, 30 per cent

biotite, and 10 per cent epidote, which suggests it was derived from an argillaceous quartz siltstone. Locally, granitic rocks are mixed with the quartzites in migmatitic and gneissic fashion.

AGE AND CORRELATION: The age and correlation of this formation are nearly as nebulous as in the case of the Upper Precambrian (?) metasedimentary rocks, because fossils are absent. The conformably overlying Prospect Mountain quartzite (Lower Cambrian ?) resembles the Stirling and Wood Canyon formations of Hazzard (1937) in the southern Death Valley region and Kingston Range. There sandstone and shale of the Johnnie formation and at least 3000 feet of Noonday dolomite underlie the Stirling and Wood Canyon formations. Thus, the limestone and dolomite formation in the Soda Mountains falls in the stratigraphic position of the Noonday and Johnnie formations. A faint lithologic resemblance was noted between the limestone and dolomite formation and the Noonday dolomite (Wright, 1954, personal communication). The thick section of Upper Precambrian Pahrump rocks in the Silurian Hills does not resemble the limestone and dolomite formation (Kupfer, 1953, personal communication).

In view of the relatively rapid facies changes of the Upper Precambrian and Cambrian rocks in the region and in view of the highly disordered condition of the rocks in the Soda Mountains, it is not surprising that there is no compelling lithologic correlation with established formations. The available evidence weakly suggests an Early Cambrian age with possible equivalence to Noonday dolomite.

Lower Cambrian(?) Prospect Mountain Quartzite

FIELD RELATIONS: The beds herein assigned to the Prospect Mountain quartzite occur only in the northern part of the Quartzite Hills (G-11). In comparison with all other stratified rocks in the Soda Mountains, this succession is the least deformed and the most readily traceable stratigraphically. The only stratigraphic marker bed of mapping value in the northeast part of the Soda Mountains is a chocolate-brown dolomite, 5–15 feet thick in the lower part of the upper member of the Prospect Mountain quartzite. In spite of the relatively ordered condition of these beds, an unbroken section is not preserved because of faulting.

The mass of quartzite that forms the bulk of the northern Quartzite Hills appears to be a klippe of folded beds cut by numerous vertical and subvertical faults. The formation lies right side up, as indicated by cross-beds, with apparent conformity on the Lower Cambrian (?) limestone and dolomite formation. No rocks overlie the Prospect Mountain quartzite in this area.

Three members are distinguished. True thicknesses are not available because of faulting, but the following minimum estimates were made in the northeast part of the Quartzite Hills: lower quartzite, 400 feet; middle quartzite, 350 feet; and upper quartzite, 1500 feet. Thus, the minimum thickness of the Prospect Mountain quartzite in the Soda Mountains is estimated as 2250 feet.

PETROGRAPHY: The beds of the Prospect Mountain quartzite are dark, finely laminated, and cross-bedded argillaceous quartzites with subordinate thin beds of siliceous dolomite and dolomitic quartzite. The lower member contains bluish-gray, impure dolomitic layers and lenses, 6 inches to 3 feet thick, interstratified with dark quartzites. In common with the underlying quartzite layers of the limestone and dolomite formation, some small areas in topographically lower rocks are variously migmatized by fine-grained quartz diorite replacement.

The middle member of the Prospect Mountain quartzite is relatively pure, massive, dense, white, vitreous quartzite. It ranges from fine-grained to conglomeratic; the clasts are round to angular, but most are recrystallized. Fine laminations reveal faint cross-bedding. A subordinate amount of feldspar is locally present.

As a whole the upper member is similar to the lower member, and the two would be difficult to separate except that a prominent and continuous chocolate-colored crystalline dolomite marker bed occurs near the base of the upper member. Also, the bluish dolomite beds, rather common in the lower member, are rare in the upper member. Throughout the 1500-foot exposed section, the upper member consists of finely laminated and cross-bedded impure quartzite. Thin sections disclose tightly interlocking grains with no remnant of matrix or clastic-particle outline. The rock consists of 95 per cent quartz, nearly 5 per cent muscovite, and traces of chlorite, biotite, and epidote. One piece of microcline appeared to be included in a quartz grain. Local granitization alters part of this member at the north edge of the Quartzite Hills (F-11; Pl. 4, fig. 2) where the rocks are structurally lower and presumably nearer underlying intrusions. The dark-gray

dolomite bed that weathers to a distinctive and uniform chocolate brown is an uncommon carbonate rock owing to high content of iron and manganese, according to analyses of the same kind of carbonate rock in the Ivanpah quadrangle (Hewett, 1956, p. 30).

AGE AND CORRELATION: Since the quartzites are unfossiliferous, age must be surmised through possible lithologic correlation with established formations in the region. The writer has observed convincing similarity between these quartzites and those in the Salt Springs Hills where they are considered by Wright and Troxel (1954, p. 43) to be the Lower Cambrian (?) Johnnie formation, Stirling quartzite, and Wood Canyon formation as used by Hazzard (1937) in the Nopah Range. The earliest Cambrian fossil zone, *Olenellus*, is high in the Wood Canyon formation, and some authorities (Wheeler, 1947) consider the underlying beds in which no fossils have yet been discovered as Precambrian. Until these formations are studied in greater detail, their age will remain uncertain. Hewett (1956, p. 38) groups the thick quartzite sequence, including the Johnnie formation, Stirling quartzite, and Wood Canyon formation, into the Prospect Mountain quartzite in the northern part of the Ivanpah quadrangle. On brief examination of the Quartzite Hills section, Hewett (Personal communication, 1954) finds notable lithologic resemblance, especially on the strength of the chocolate-colored dolomite layer, to the Prospect Mountain rocks in the Kingston Range. On the basis of these correlations the quartzite is considered to be part of the Prospect Mountain quartzite of Early Cambrian (?) age.

Cambrian strata are well known and described in several places within 100 miles of the Soda Mountains. In the Goodsprings quadrangle, Hewett (1931, p. 11) measured 130 feet of fossiliferous Lower Cambrian Prospect Mountain or Tapeats sandstone. This thin section thickens enormously below the *Olenellus* zone in a westward direction to about 3600 feet on the northeast flank of the Kingston Range (Hewett, 1956, p. 31) and 8200 feet in the Nopah Range (Hazzard, 1937). Several thousand feet of Lower Cambrian (?) quartzite, the upper portion of which is fossiliferous, is noted by Hopper (1947, p. 403–408) in the Panamint Range and by Knopf and Kirk (1918, p. 26–31) in the Inyo Range. South of the Soda Mountains the Cambrian rocks are considerably thinner than they are to the north. In the Providence and Marble mountains, Hazzard and Crickmay (1933) have described about 1100 feet of fossiliferous Lower Cambrian quartzite, which rests unconformably on Lower Precambrian metamorphic rocks. Seventy-five feet of unfossiliferous quartzite with lithologic character and basal unconformity matching the Cambrian in the Marble Mountains is reported by Gardner (1940, p. 264–265) in the Newberry Mountains. The quartzite is in an exposure nearly surrounded by alluvium. Exposures beyond the alluvium are Mesozoic granitic rocks or Precambrian metamorphic rocks.

In the Soda Mountains, the 2250 feet (minimum) of Lower Cambrian (?) quartzite appears to be intermediate in thickness between the thinner sections southward and the thicker sections northward.

Relations of the Precambrian(?) and Lower Cambrian(?) Rocks

General features common to this group of rocks in the Soda Mountains are: (1) they occur in relatively close spatial association in the field; (2) their over-all lithology is unique compared to other formations in the Soda Mountains; (3) these rocks have reacted in correspondingly similar fashion to varying degrees of metamorphism, granitization, and tectonic deformation. These features strongly suggest that the metasedimentary rocks in the four formations constitute a single, thick, continuous, sedimentary sequence which has been tectonically dislocated and variously metamorphosed and intruded.

The Soda Mountains lie in the transition zone between the eastern Mojave Desert, where metamorphic and migmatitic rocks are locally proved to be Lower Precambrian, and the central Mojave Desert where they are shown to be in part metamorphosed Upper Paleozoic sedimentary rocks (Bowen, 1954, p. 17–42; McCulloh, 1954, p. 15). Thus the problem of correlation of these metamorphic rocks in the Soda Mountains is accentuated.

Pre-Mesozoic Carbonate Rocks, Undifferentiated

FIELD RELATIONS: Isolated masses of intimately mixed dolomite and limestone are scattered through the hills east of the Soda-Avawatz fault zone. Small masses of buff dolomite roof pendants in granodiorite are clearly visible on Hopeless Hill from the highway near Baker. The spectacular contrast of orange on black displayed on Dolomite Mountain (Pl. 4,

fig. 1) is due to extremely irregular plutonic invasion of this carbonate unit.

As a whole the carbonate rocks are believed to be allochthonous in the Soda Mountains. They are in thrust contact over the Precambrian (?) gneissic complex, as verified by structural discordance and shearing, and they are in igneous contact with the pre-Tertiary plutonic rocks. The Cretaceous Teutonia quartz monzonite forms an abnormally flat contact with the carbonate mass in the Moonshine area; the flatness of the contact is attributable to intrusion along a flat thrust. Within this carbonate unit the beds are isoclinally folded, sheared, and brecciated; they are structurally out of harmony with other rocks in the region. Such conditions preclude accurate measurement of the stratigraphic thickness, but the section appears to be several thousand feet thick.

PETROGRAPHY: The undifferentiated carbonate formation is composed entirely of crystalline dolomite, limestone, and all gradations between the two. Characteristically it is finely laminated dark and light (buff) brown and locally gray and white (Pl. 5, fig. 1). Almost without exception the gray carbonate beds are limestone. The brown and white beds on most outcrops tested with acid in this formation showed extremely irregular and usually unpredictable distribution of dolomitic and limy sedimentary rocks.

Within several score feet of plutonic intrusive rocks, forsterite, spinel, and antigorite are developed in disseminated small crystals and in fractures, but the contact with intrusive rocks is sharp in most places and lacks massive formation of contact-metamorphic minerals. A notable exception, however, is in the Moonshine area where quartz monzonite has intruded brecciated limestone producing scheelite-bearing garnet tactite irregularly along the contact.

AGE AND CORRELATION: This carbonate unit lacks fossils and joins other formations by thrust or intrusive contacts. Since the Teutonia quartz monzonite intrudes it, it is pre-Cretaceous.

On the basis of lithology and field occurrence, the writer has correlated the formation with a carbonate unit designated as Paleozoic undifferentiated by Hewett (1956, p. 46–47) and occurring in a rather limited area about 5 miles east of Silver Lake. In the Silurian Hills (Kupfer, 1952, Ph.D. thesis, Yale Univ.), the Paleozoic (?) Riggs formation, a plate of limestone and dolomite, appears to bear some lithologic resemblance to the carbonate unit in the Soda Mountains. Just east of the Silver Lake camp are carbonate rocks (B-17) that Miller (1946, p. 499) considers an integral part of the Halloran complex to which he has assigned an Early Precambrian age.

For the following reasons, the age of this carbonate unit is considered to be Early or Middle Paleozoic and almost definitely pre-Mesozoic: (1) Thick Mesozoic carbonate rocks are unknown in the region. (2) Thick, fossiliferous, gray limestones of Late Paleozoic age occur in the Soda Mountains. They do not resemble the carbonate rocks in question. (3) The carbonate rocks show no resemblance to the Upper Precambrian Pahrump sedimentary rocks. (4) Thick carbonate bodies seem to be rare in Lower Precambrian rocks. (5) Dolomites in other parts of the region are most abundant in Lower and Middle Paleozoic sedimentary rocks. (6) The most logically correlative units are the Paleozoic undifferentiated unit of Hewett in the Ivanpah quadrangle and the Paleozoic (?) Riggs formation of Kupfer in the Silurian Hills.

Mississippian-Pennsylvanian(?) Limestone

FIELD RELATIONS: A gray and white nonuniform limestone section is differentiated (locally with great difficulty) from two other limestone units on Spectre Spur in the northwest part of the Soda Mountains. This formation occurs isolated on the east side of Spectre Spur in two prominent, resistant knobs (L-7), on the west side in a complex of thrusts (N-5; Pl. 3; Pl. 6, fig. 2; Pl. 7, fig. 1), and on Zzyzx Hill. The formation is so intricately faulted that a normal stratigraphic section is nowhere preserved, nor can one be pieced together. Indirect evidence suggests that this unit, as well as the other Upper Paleozoic formations, was thrust into the Soda Mountains region.

The masses on the east side of Spectre Spur are remnants of vertical isoclinal folds, and the entire sequence is faulted against Mesozoic metavolcanic rocks and against Permian limestones. They are terminated downward by intrusive contact with Upper Mesozoic quartz monzonite. The limestone on the precipitous west side of Spectre Spur is questionably correlated with that on the east side, although it has many lithologic features in common with two younger limestone formations. It underlies a thrust plate of Bird Spring limestone and incorporates a lower thrust zone of chaotic blocks and slices (Pl. 3; Pl. 6, fig. 2; Pl. 7, fig. 1). The beds dip steeply east or are vertical. The

base of this formation is cut out by faulting against Mesozoic volcanic rocks, and the upper limit is concealed by the thrust. Therefore, the stratigraphic thickness is indeterminate, but it appears to be at least 1500 feet.

PETROGRAPHY: The section on the west side of Spectre Spur consists, from the lower part to the upper part, of the following three units: (1) massive to thick-bedded, light limestone with some thick, buff dolomite and dark-gray limestone beds and thin-bedded continuous cherty layers; (2) thick- to thin-bedded alternating gray and white limestone with nodular chert; (3) predominately medium- to thin-bedded, gray limestone with abundant thin chert layers and nodules. The limestone blocks on the east side of Spectre Spur consist of the types of rocks found low in the section.

The texture varies from coarsely to finely crystalline, and at places clearly discernible clasts remain. Crinoid stems are locally preserved. Small-scale recrystallized silica and calcite occur widely because of omnipresent faulting and metamorphic effects of granitic and volcanic intrusion.

AGE AND CORRELATION: The age of the limestone formation is unknown. A few crinoid stems in the upper part supply meager evidence for probable Middle or Late Paleozoic age. In gross lithologic aspect the formation resembles the Pennsylvanian-Permian Bird Spring formation. The two formations are also closely associated spatially.

On the basis of cursory examination of Upper Paleozoic rocks in the Ivanpah quadrangle and descriptions in the literature, this limestone is believed to correlate roughly with the Mississippian Monte Cristo limestone of the Goodsprings area (Hewett, 1931, p. 17–21) and in the Nopah Range (Hazzard, 1954a).

Mississippian-Pennsylvanian(?) Limestone and Hornfels

FIELD RELATIONS: One of the most complex formations in the Soda Mountains consists of limestone, hornfels, and subordinate quartzite. The formation is distributed in isolated and intruded fault blocks, which are confined to the area within and west of the Soda-Avawatz fault zone (Pls. 1, 10).

The thickest section occurs with steep east dip stratigraphically overlying—by interpretation (Pls. 1, 10)—the Mississippian-Pennsylvanian (?) limestone and structurally underlying the klippe of Permian Bird Spring limestone on Spectre Spur (M-6; Pl. 7, fig. 2). The section is intricately chopped into numerous fault blocks, so that accurate measurement of lithologic succession is impossible. It contains more quartzite and less hornfels than other sections to the south.

Another large mass of this formation occurs in a squeezed-up wedge within the Soda-Avawatz fault zone (Q-11). Here the beds are vertical and subvertical. Extreme structural confusion has resulted from folding, faulting, and intrusion—a condition that prevents rewarding stratigraphic study.

Smaller faulted and intruded blocks of this formation occur in other areas; *i.e.*, southwest side of Spectre Spur (O-4), northern end of Granite Ridge (N-7, 8), southern end of Granite Ridge (Q-10), Blue Bell Mine area (S-8), and Highway Spur (R-11, S-12). The formation in these areas contains more banded hornfels and less quartzite.

Stratigraphic marker beds are nonexistent; hence, structural relations between the fragmentary sections as well as within each section could not be deciphered. However, the bedding in all the scattered blocks is generally vertical to steeply east-dipping and striking north to northwest. The remnants of this formation, together with the other two Upper Paleozoic limestone formations, form part of an allochthonous mass, which has been thrust over the Mesozoic Soda Mountain formation. The plate was intricately block-faulted and then passively intruded by Late Mesozoic plutonic magmas.

Where this formation lies in igneous contact with the Upper Mesozoic granitic rocks, garnet tactite occurs in enormous masses and in selected beds. Thin limestone beds in hornfels are nearly completely garnetized for many hundreds of feet from the contact. Locally, masses of greenish-brown garnet surrounded by hornfels attest the former presence of limestone in the invaded rocks. These features are particularly well shown along the old road in the Blue Bell Mine area.

The original stratigraphic thickness of this unit is impossible to ascertain accurately in the Soda Mountains, but a minimum thickness of at least 1 mile is estimated from what is believed to be an essentially unrepeated section on Spectre Spur. The total original thickness was undoubtedly much greater.

PETROGRAPHY: The most abundant rock is unfossiliferous, finely to medium-crystalline, white to dark-gray limestone. It occurs as the predominant rock for as much as 100 feet vertically at some places, but in many places it gives way to less uniform limestone and

bedded chert, or quartzite, chert, and limestone. In hornfels-rich portions of this formation, most of the limestone takes a subordinate position in thinner but distinct beds.

The rocks designated as hornfels are extremely fine-grained, uniform to finely banded, and very dense. The finely laminated hornfels is greenish gray and tan, and the laminae range from 1 mm to about 40 mm (Pl. 4, fig. 3). The uniform hornfels is difficult to distinguish from some of the thermally metamorphosed nonporphyritic andesitic rocks which contact it in places. Originally, the hornfelses were probably silica-rich marl. Thin sections of typical banded hornfels showed extremely fine-grained mixtures of quartz, epidote, actinolite, and calcite. The dark laminae are rich in epidote, and the light laminae contain more quartz.

Very fine-grained quartzite is locally abundant in this formation, especially on Spectre Spur. It occurs in brown and gray beds, 3 inches to 100 feet thick, with limestone, chert, and very minor amounts of hornfels. The cryptocrystalline silica rocks are classified as chert, and the finely granular silica rocks are called quartzite. Identification of some of the siliceous sedimentary rocks is extremely difficult, since deformation and metamorphism have locally obliterated the original features of the hornfels, quartzite, and chert.

Continuous beds of dark-brown to gray chert from half an inch to 5 feet thick are interbedded with limestone of this formation in some localities, such as the north end of Highway Spur (Q-11). The chert is resistant to weathering and extremely dense. A thin section shows that much of the silica is cryptocrystalline to very fine-grained. Hematitic stain pervades most of the rock.

In summary, two slightly different lithologic associations are recognizable in the scattered and disconnected masses of this formation. One is rich in hornfels and limestone; the other is rich in quartzite, chert, and limestone. However, the relative amounts of hornfels, quartzite, and chert are difficult to determine in many places, since the original lithology is locally obscured by metamorphism.

The limestone and hornfels of this formation show so much lithologic resemblance to portions of the underlying limestone and overlying (?) Bird Spring formation respectively that formational separation in the most structurally complex and most metamorphosed areas was necessarily arbitrary. The presence of banded hornfels served as the most reliable single criterion for identification of this formation.

Rocks of this formation are everywhere thermally metamorphosed by the Late Mesozoic granitic intrusions. Mineral assemblages produced by contact metamorphism and hydrothermal alteration are abnormally prevalent in the invaded rock. According to Hewett (Personal communication, 1953), the contact metamorphic rocks in the Soda Mountains are among the most extensive in the Mojave region. Thick limestone beds have been converted to *masse* to garnet (mainly grossularite) tactite. The marls, which have been converted to very dense hornfels, are variously epidotized, in some places to nearly pure epidote rock. Small-scale copper, lead, and silver mineralization is evident in scattered shear zones in the tactite and hornfels.

AGE AND CORRELATION: Organic remains have not been discovered in the limestone and hornfels formation. Structural relations on Spectre Spur suggest that this formation stratigraphically overlies the crinoid-bearing Mississippian-Pennsylvanian(?) limestone formation (Pls. 1, 10). The facts that all three Upper Paleozoic formations are closely allied lithologically and are inextricably involved in a great thrust complex strongly imply that they were integral parts of a single, thick, stratigraphic succession.

As in the case of the underlying limestone formation, this formation cannot be confidently correlated with any other section in the Mojave Desert. In thickness, lithology, deformation and metamorphism, it seems to fill a position between the Monte Cristo—Bird Spring section in the eastern Mojave region (Hewett, 1956, p. 42–45) and the Upper Paleozoic Oro Grande and Fairview Valley formations in the central Mojave region (Bowen, 1954, p. 23–42), although it more closely resembles the rocks in the eastern region.

Lower Permian Part of the Bird Spring Formation

FIELD RELATIONS: The Bird Spring formation occurs in a highly disordered condition as a thrust plate on top of Spectre Spur (Pl. 6, fig. 2; Pl. 7) and on Baker Hill. The Spectre Spur klippe overlies the two Mississippian-Pennsylvanian formations and laterally is in contact with the Soda Mountain formation along great subvertical faults. On Baker Hill it appears to rest with igneous contact on pre-Tertiary quartz diorite.

The formation is characterized by widespread internal faulting and brecciation (Pl. 7, fig.

Pl. 8, fig. 3). This fact, coupled with a dearth of marker beds, permits recognition of only the broad lithologic aspect of the formation. Individual beds can be traced not more than about 200 feet and in most places not more than 20-50 feet. Detailed structural and stratigraphic mapping on Baker Hill revealed that large portions of the formation are in tectonic chaos that precludes piecing together any members or deriving a convincing over-all depositional pattern. The condition at Baker Hill is identical to that in the large mass on Spectre Spur, except that the latter area has a prevailing steep east dip.

Several thick fusulinid zones occur; they may represent portions of a larger fusulinid limestone section. Utilization of these fossil beds as stratigraphic markers in the Bird Spring formation may be feasible in the event of very detailed study of the thrust complex.

Since the Bird Spring formation is the uppermost thrust mass preserved in the complex on Spectre Spur, it is farthest from the intrusive quartz monzonite and consequently least altered. It is also one of the two limestones in the Soda Mountains in which diagnostic fossils occur. Possibly, then, the other limestone formations once contained diagnostic fossils that are now obliterated by metamorphism due to proximity to the intrusive rocks.

The largest mass of the Bird Spring formation in the Soda Mountains area constitutes the klippe on top of Spectre Spur. The klippe contains at least 5000 feet of east-dipping beds; it is not certain how much, if any, of the section is repeated or cut out by faulting. Field relations (discussed below) disclose that the Bird Spring formation and the other Paleozoic limestones once covered the Soda Mountains area as a great allochthonous thrust complex. The largest remnant is the giant downfaulted block on Spectre Spur.

PETROGRAPHY: The Bird Spring formation in the Soda Mountains is essentially a monotonous sequence of thin- to medium-bedded, dark- to light-gray clastic (originally) limestone. Chert is abundant in nodules, lenses, or continuous beds. The fusulinid limestone layers usually occur in a cyclical succession with chert and barren limestone (Pl. 4, fig. 4). Pure dolomite is subordinate, but partially dolomitized limestone is very common. Dolomite shows all stages of replacement by irregular patterns of buff color within selected beds. At the summit of Spectre Spur is several hundred feet of hard, dense, calcareous siltstone and shale, which is not present on Baker Hill. These rocks have a very fine-grained to cryptocrystalline texture and some faint banding which resembles that in the more siliceous banded hornfelses of the limestone and hornfels formation. Thin sections of the calcareous siltstone show principally angular quartz clasts of uniform size, slightly smaller than $\frac{1}{16}$ mm, imbedded in a matrix of barely distinguishable calcite, epidote, sericite (?), and chlorite (?).

Internal chaotic faulting has encouraged reprecipitation of calcite, forming white, coarsely crystalline veins (1 inch to 30 feet wide) in numerous fracture zones. Silica derived from chert apparently has been locally redistributed and concentrated as cementing material in breccia.

AGE AND CORRELATION: Two beds on Spectre Spur yielded the genus *Schwagerina* (Pl. 4, fig. 4). On Baker Hill *Schwagerina* and possibly *Triticites* were discovered. The rocks locally derived from the Bird Spring formation which constitute giant landslide masses in the Avawatz formation yielded *Schwagerina* and probably *Triticites*. *Syringopora* are locally abundant in scattered areas.

The presence of *Schwagerina* confirms a Permian age and, together with *Triticites* (?), strongly suggests Early Permian (Thompson, 1948).

Other fossils occur abundantly—tetracorals, echinoid spines, crinoid stems, bryozoa, small gastropods, and many fusulinids—but they are too fragmented, deformed, and recrystallized for diagnosis.

The presence of Upper Paleozoic carbonate rocks in the Soda Mountains region has been known for a long time. On Baker Hill, Thompson (1929, p. 557) collected some poorly preserved fossils of Carboniferous (?) age. On the same hill, Miller (1946, p. 500) found crinoid remains which were pronounced Carboniferous and probably Mississippian. Hewett (1956, p. 45) discovered Permian (?) fusulinids on Spectre Spur in 1948.

Upper Paleozoic sections are described by Hewett (1956, p. 42–47) in the Ivanpah quadrangle, by Longwell and Dunbar (1936) in the Las Vegas quadrangle, by Hazzard (1954a) in the Nopah Range, and by Thompson, Wheeler, and Hazzard (1946, p. 37–40) in the Providence Mountains. On the basis of these written descriptions, the Bird Spring formation appears to bear some lithologic and paleontologic resemblance to the fusulinid limestones in the Soda Mountains. Hewett (Personal communication, 1953) suggested that some of the limestone on Spectre Spur lithologically resembles

the Bird Spring rocks in the Goodsprings area. In view of the above suggestions, it seems reasonable to apply the term Bird Spring to these rocks in the Soda Mountains.

The Anvil Spring formation of Johnson (1957, p. 382–384) in the southern Panamint Range is suggested as an equivalent of the Bird Spring formation, since a striking lithologic correspondence between it and the Bird Spring rocks in the Soda Mountains area has been noted. The Keeler Canyon formation and the lower part of the Owens Valley formation in the Argus Range and the southern Inyo Mountains (Merriam and Hall, 1957) appear to be correlative with the Bird Spring in the Soda Mountains.

In the type section of the Bird Spring formation, the Spring Mountains of southwestern Nevada, Longwell and Dunbar (1936, p. 1202) have demonstrated that more than half of the formation falls into the Permian system and the rest into the Carboniferous. How much, if any, of the formation in the Soda Mountains is Pennsylvanian is unknown, because of the lack of orderly sections and the lack of sufficient diagnostic fossils. However, probably most, if not all, of the incomplete formation in the Soda Mountains can be safely assigned to the Lower Permian, since *Schwagerina* beds occur in several zones well distributed through the 5000 feet of section.

Relations of the Upper Paleozoic Sedimentary Rocks

In the Soda Mountains, the three formations assigned to the Carboniferous and Permian systems show some features in common: (1) The three units are essentially alike in gross lithology; they are primarily cherty gray limestone with subordinate beds of marl and quartzite. This suggests that they were once part of a thick and uninterrupted stratigraphic succession. (2) The three formations are intimately involved in a great allochthonous complex, which implies that they may have been once closely associated, especially since no other formations are directly involved. (3) The rocks seem to have yielded to deformation and metamorphism in similar fashion. (4) All three formations display, in general, a higher degree of lithologic correspondence with the Mississippian Monte Cristo and Pennsylvanian-Permian Bird Spring succession than with other strata in the region.

A glance at the regional relations of Carboniferous and Permian rocks reveals that, if conjectures about the age and thickness of th Carboniferous (?) and Permian rocks in th Soda Mountains and the southwestern regi are correct, the Soda Mountains section transitional between thin miogeosynclinal sed mentary rocks to the east and northeast an thick eugeosynclinal sedimentary rocks to th west and southwest. The following sections Carboniferous and Permian rocks have be studied in the region generally to the northea of a zone extending northwest and southeast the Soda Mountains:

	(Feet)
Providence Mountains (Hazzard, 1954b)	3635–38
Ivanpah quadrangle, northwest part (Hewett, 1956) not including Supai and Kaibab formations	1550–32
Goodsprings quadrangle (Hewett, 1931)	2880–37
Nopah Range (Hazzard, 1954a)	2685+

Characteristic of these sections are: (1) pr dominance of limestone, (2) minor amount detrital rocks, (3) abundance of fossils, (absence of volcanic flows and tuffs, (5) absen of severe deformation, and (6) absence regional metamorphism.

The following data are summarized for t rocks which are known or suspected to Upper Paleozoic in the region southwest a west of the Soda Mountains:

	(Feet
El Paso Mountains (Dibblee, 1952)	35,00
Calico Mountains (McCulloh, 1954)	25,00
Barstow quadrangle (Bowen, 1954)	30,00

Properties common to these sections are: predominance of detrital rocks, (2) subordina volume of carbonates, (3) rare preservation fossils, (4) presence of volcanic flows and tuf (5) widespread severe tectonic deformati and (6) regional metamorphism, migmatizati and intrusion.

For comparison with the above, the C boniferous (?) and Permian rocks in the So Mountains exhibit the following features: estimated thickness of 11,500 feet, (2) p dominance of limestone, but presence of c siderable clastic sedimentary rocks, (3) po preserved fossils, (4) lack of volcanic rocks, possible content of tuffaceous material in siltstones and shales, (5) severe deformati but no metamorphic foliation, and (6) wi spread thermal metamorphism near intrusi These features suggest that the Upper Pa zoic rocks in the Soda Mountains are tr

ional in thickness (?), lithology, deformation, and metamorphism between rocks of the same general age to the east and northeast and to the west and southwest. They resemble the eastern rocks more than the western, however, which implies that the transition zone lay largely to the west and southwest of the Soda Mountains.

The intermediate features displayed by the Upper Paleozoic rocks indicate that during Late Paleozoic time the Soda Mountains were situated between miogeosynclinal and shelf environment to the east and eugeosynclinal environment to the west. This coincides roughly with the proposed position of transition from a "mainland assemblage" on the east to an orogenic and volcanic environment on the west (Eardley, 1947, p. 337).

Lower Triassic Sedimentary Rocks

FIELD RELATIONS: Sedimentary rocks of Early Triassic age are preserved in two small fault blocks low on the west side of Spectre Spur (L, M-5). The area consists of a mosaic of fault blocks involving volcanic rocks of the Soda Mountain formation and felsite porphyry. The base and lower part of the sedimentary sequence are faulted out; the sedimentary rocks are in fragmentary fault blocks, but at one place (L-5) an unfaulted contact reveals the top of the section. This contact, which is exposed for about 800 feet, is a disconformity between the Lower Triassic clastic sedimentary rocks and the overlying andesitic flow breccias, interbedded sandstones, and pyroclastics of the Triassic-Jurassic Soda Mountain formation.

The section is complicated by numerous intrusions of Tertiary dikes and plugs and by varying degrees of thermal alteration, which is especially manifest in breccia zones. In spite of the effects of faulting and intrusion, the Triassic beds, totaling nearly 1700 feet in thickness, dip steeply eastward in general accordance with other units on Spectre Spur, including the allochthonous Paleozoic sedimentary rocks. They are probably para-autochthonous rocks with respect to the thrust complex.

PETROGRAPHY: The sedimentary rocks herein assigned to the Early Triassic constitute a unique assemblage in the Soda Mountains. They consist of thin layers of gray, in part nodular, limestone interbedded with distinctive red, green, and gray argillite and shale.

The following section was measured by pace and Brunton traverse through the least faulted and intruded portion of the section:

	Thickness (Feet)
oda Mountain formation	
Andesitic flow breccia, purple and gray, locally green; porphyritic, irregularly altered, interbedded with fine, dark-red sandstone	
isconformity; at least 10 feet of gentle relief exposed	
ower Triassic rocks	
Argillite, gray, locally green and red; grades into interbeds with siltstone and fine-grained faintly cross-bedded sandstone near top, locally highly fractured and altered. Mostly nonmarine sedimentary rocks	650
Limestone, gray, finely crystalline; contains discontinuous irregular laminae of iron-bearing chert, $\frac{1}{16}$–$\frac{1}{2}$ inch thick and $\frac{1}{4}$–2 inches apart	3
Argillite, gray, clayey; with minor reddish and greenish areas, generally uniform	25
Limestone, as above	4
Argillite, as above	30
Limestone, as above	4
Argillite, as above	15
Limestone, brown and gray, finely crystalline; with iron-bearing chert nodules and lenses 1 inch to 1 foot long	5
Argillite, as above	35
Limestone, gray, finely crystalline, massive; with few scattered 1- to 3-inch iron-bearing chert nodules	7
Argillite, as above	20
Limestone, brown and gray, finely crystalline; with iron-bearing chert stringers, $\frac{1}{8}$–2 inches thick	3
Limestone, medium gray, fine to medium crystalline, uniform, massive, rarely cherty	7
ault; about 50 feet of beds obscured	
Argillite, as above	20

	Thickness (Feet)
Limestone, gray, finely crystalline; with abundant iron-bearing chert in small nodules	
Argillite, as above	
Limestone, gray, finely crystalline, locally conglomeratic; contains broken laminae of iron-bearing chert and gastropods	
Fault; about 100 feet of section obscured	
Argillite, as above	
Limestone, brownish gray, finely crystalline; contains small irregular iron-bearing chert nodules and lenses	
Argillite, as above	
Limestone, as above	
Argillite, gray, calcareous	
Limestone, as above	
Argillite, as above	
Limestone, brownish gray, finely crystalline; upper 2 feet of finely interbedded shale and limestone; lower 2 feet are nodular with iron-bearing chert surrounding 1- to 3-inch limestone nodules	
Fault; obscures 50–100 feet of section	
Shale, gray, reddish and greenish in a few places, minutely jointed	
Limestone, brownish gray, finely crystalline; limestone in 1- to 3-inch ovoid nodules surrounded by thin layer of iron-bearing cherty material	
Shale, grayish red and green; minutely jointed into long "pencils"	
Shale, as above, limy in part; contains (near the top) numerous 2-inch to 1-foot beds of brownish gray, nodular, ferruginous, and cherty gastropod-bearing limestone (Pl. 5, fig. 3)	
Fault; at least 100 feet of section obscured	
Shale, as above, but without limestone beds	
Limestone, medium gray, very finely crystalline, relatively pure	
Shale, gray, limy	
Limestone, medium gray to buff, very finely crystalline, thin- to medium-bedded, relatively pure; interbedded with tan and gray limy shale in ½-inch to 1-foot beds. Limestone constitutes about 70 per cent of unit and increases in amount downward	
Fault; cuts out an unknown amount of section	
Tertiary intrusive felsite porphyry and Triassic-Jurassic andesitic flow breccia	
Total thickness of exposed Lower Triassic sedimentary rocks (This is a minimum figure.)	167

A very distinctive pebble conglomerate, containing pink, gray, buff, and white limestone clasts, occurs locally in complex fault relation with the Triassic section. No evidence has been found for its age and stratigraphic position. Since it resembles a Triassic conglomerate in the southern Panamint Range (Johnson, 1957, p. 385–386), it is here considered part of the Triassic sequence lower than the relatively ordered succession described above.

Upward in the Triassic section, limestone is less abundant and becomes nodular, cherty, and ferruginous, whereas the lower limestones are nearly pure. The cherty portions may be high in siderite and possibly phosphate. The shale-argillite fraction increases in volume upward in the section, and very near the top it becomes silty and sandy. The sand is rich in fine clasts of andesite. The term argillite is used where the shale is highly indurated, jointed, and

PLATE 2.—SODA MOUNTAINS, VIEW SOUTHWESTWARD

The Soda-Avawatz fault zone extends from middle left to lower right. F_1—East fault; F_2—prominent fault; F_3—West fault. pCg—Precambrian(?) gneiss; IPhl—Upper Paleozoic limestone and hornfels; Mav—Mesozoic metavolcanic rocks of the Soda Mountain formation; Mgr—Upper Mesozoic granite; Tal—Pliocene fanglomerate of the Avawatz formation containing resistant limestone breccia masses. 1—Highway Spur; 2—Zzyzx Hill; 3—Granite Ridge

PLATE 3.—THRUST ZONE IN UPPER PALEOZOIC LIMESTONE

Greatly disorganized bedding in thrust zone within Mississippian-Pennsylvanian(?) limestone formation on west side of Spectre Spur (N-4). Avawatz Mountains are in far background to left.

SODA MOUNTAINS, VIEW SOUTHWESTWARD

THRUST ZONE IN UPPER PALEOZOIC LIMESTONE

FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

PALEOZOIC ROCKS

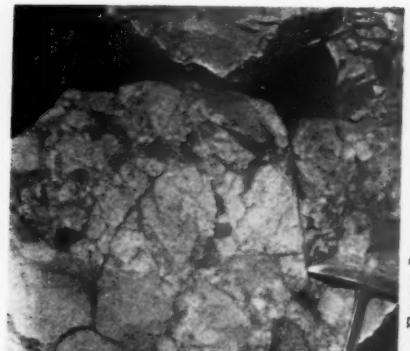

FIGURE 2

FIGURE 4

FIGURE 1

FIGURE 3

altered principally because of thermal metamorphism. The gross lithologic variation upward in the section to the disconformably overlying andesite breccia suggests a transition rather than an abrupt change from marine to continental depositional environment.

AGE AND CORRELATION: Some tiny gastropods, seldom more than 1 mm in greatest diameter, were discovered by J. F. McAllister in 1953 about 650 feet above the base of the exposed Triassic section (Pl. 5, fig. 3). Merriam contributed the following statement about these gastropods (1958, written communication):

"Minute gastropods and fillings of gastropod shells having the general form of *Hydrobia* are characteristic of the lowermost Triassic or *Ussuria* zone of the southern Inyo Mountains, California. They frequently occur in vast numbers in rather impure limestones; the gastropod fillings are phosphatic. Similar minute gastropods in large numbers have been noted in Triassic beds of the Providence Mountains and other Triassic exposures of western North America. Other occurrences of such fossils in great numbers appear to be Late Permian. Whether these gastropods represent larvae or mature individuals is not known. Association with the ammonoid *Ussuria* indicates a marine environment for the Inyo Mountains occurrences, but such minute shells could easily be transported by winds. The small gastropods from the Soda Mountains appear to be identical to those from the Inyo Mountains *Ussuria* zone, suggesting that they too are early Triassic. However, the possibility that the Soda Mountains occurrence may be later Triassic or even Permian cannot be eliminated."

The 800 feet of beds exposed below the fossil zone is tentatively regarded as Lower Triassic, since they are in continuous stratigraphic succession with the fossiliferous beds and since they are unlike the Upper Paleozoic rocks in the region.

Correlative sections of Early Triassic age occur in a northwest-southeast line through the Soda Mountains extending from the Inyo Range to the Providence Mountains. The stratigraphic section in the Inyo Range (Knopf and Kirk, 1918, p. 47–48) resembles the Soda Mountain section (McAllister, 1953, personal communication) with regard to lithology and field relations. The Lower Triassic Moenkopi formation in the Providence Mountains (Hazzard, 1954b, p. 28) consists of about 1000 feet of limestone, shale, and subordinate sandstone, that, judging from the published description, resembles the Soda Mountain section. More than 4000 feet of Lower (?) Triassic strata bearing ammonites in one zone was mapped recently by Johnson (1957, p. 384–388) in the southern Panamint Range. On the basis of a cursory field examination and the written description, the writer concludes that a part of the Panamint section coincides lithologically with Lower Triassic sedimentary rocks on Spectre Spur.

The nearest known Lower Triassic rocks northeast of the Soda Mountains are in the Ivanpah quadrangle (Hewett, 1956, p. 47–48) where the Moenkopi formation is recognized. Although there is no compelling lithologic basis for extending the Moenkopi formation westward, the Soda Mountain section may represent a western equivalent of the Moenkopi.

In the region west and southwest of the Soda

PLATE 4.—PALEOZOIC ROCKS

FIGURE 1.—View northwestward of Dolomite Mountain (D-12). Middle Paleozoic(?) limestone and dolomite formation occurs as roof pendants in basic plutonic rocks.

FIGURE 2.—Local granitization in the upper member of the Prospect Mountain quartzite (F-11). Light rocks are granitized.

FIGURE 3.—Banded hornfels of the Mississippian-Pennsylvanian(?) limestone and hornfels formation (R-8)

FIGURE 4.—Interbedded chert (by hammer head), barren limestone, and fusulinid limestone of the lower Permian part of the Bird Spring formation on Spectre Spur (M-5)

PLATE 5.—PALEOZOIC AND MESOZOIC ROCKS

FIGURE 1.—Middle Paleozoic(?) limestone and dolomite, relatively undeformed (0–13)

FIGURE 2.—Andesite flow breccia of the Triassic-Jurassic Soda Mountain formation. Volcanic clasts shown here are a little larger than average size.

FIGURE 3.—Lower Triassic gastropod-bearing nodular limestone interbedded with "pencil shale"

FIGURE 4.—Sandstone beds within the Soda Mountain formation (T-13). Dark beds are volcanic sandstone; light beds are quartz-rich sandstone. Note cross-bedding in upper right.

Mountains, Lower Mesozoic rocks dated on paleontologic grounds are unknown except for the Bedford Canyon formation in the Santa Ana Mountains (Larsen, 1948, p. 18–22). In the Lane Mountain quadrangle east of Barstow, McCulloh recently discovered in hornfelsic quartzite some poorly preserved pelecypods which suggest a Late Triassic age (N. J. Silberling, 1955, personal communication). The unfossiliferous Bean Canyon metasedimentary rocks in the Elizabeth Lake quadrangle in the western Mojave Desert resemble Triassic rocks in the Inyo Range (Simpson, 1934, p. 381–383). West of Goldstone Lake, about 25 miles north of Barstow, is 5000 feet of sedimentary rocks, which according to McCulloh are similar to the Triassic exposed in the Inyo Range (*in* Hewett, 1955, p. 381).

Triassic-Jurassic Soda Mountain Formation

DEFINITION AND FIELD RELATIONS: A thick series of volcanic flow breccia and sandstone, for which the name Soda Mountain formation is herein proposed, forms a prominent and widespread mappable unit in the Soda Mountains. The north end of Spectre Spur (K-5) is selected as the type location for the formation, even though the section appears unsuitable because of a high degree of faulting and alteration. Yet the Spectre Spur section is the most nearly complete, most orderly, and least metamorphosed and intruded of any in the Soda Mountains or immediate surroundings. A representative stratigraphic section is impossible to find for the following reasons: (1) extreme and capricious lateral and vertical lithologic variation, (2) presence of many internal erosional contacts, (3) destruction of original rocks by hydrothermal alteration, (4) absence of marker beds, (5) complexity of structural deformation, and (6) complexity of hypabyssal and plutonic invasion. The Spectre Spur section disconformably overlies Lower Triassic sedimentary rocks and is faulted laterally against Upper Paleozoic limestones. A minimum thickness of 7000 feet is estimated, but probably the formation was originally highly variable from place to place and locally much thicker than the Spectre Spur section.

The large area of Soda Mountain formation in Highway Spur (T-13) is of critical importance, since the thick interbeds of sandstone there are correlated lithologically with the Jurassic (?) Aztec formation at Mountain Pass, 40 miles northeastward.

The Soda Mountain formation displays little bedding, except where interbedded sandstones and pyroclastics occur. Thus over large areas the structure is almost unknown. However, where bedding is visible, it is steep, vertical, or locally overturned. The formation is generally bound in complex fault-block relations by the Upper Paleozoic limestone formations and is intruded by Upper Mesozoic plutonic rocks.

The Soda Mountain formation is also present in surrounding areas, which have been examined in reconnaissance only. At least 2500 feet of andesitic and dacitic flow breccias in the Soda Mountain formation is exposed in Zzyzx Hill. The Red Pass Range is largely made up of metavolcanic rocks which are probably part of the Soda Mountain formation.

PETROGRAPHY: The rocks composing the Soda Mountain formation range from massive andesite flows through flow breccia, pyroclastic rocks, and welded tuff to volcanic sandstone and, finally, to nearly pure quartzite. Relative abundance of each type varies extremely and unpredictably within short distances vertically and laterally, but volumetrically the flow breccia predominates and is followed by volcanic sandstone. Massive flows, welded tuff, and pure quartzite are only locally abundant. The transitional relationship among the rock within the Soda Mountain formation illustrates varying amounts of erosion, deposition, weathering, and dilution of original volcanic rock with sedimentary rocks—all of which affected the formation of this complex and heterogeneous series.

The volcanic rocks are reddish purple and clearly porphyritic in fresh samples but are mottled greenish gray and only faintly porphyritic in altered rocks (greenstones). Individual fragments in the breccia, best seen on water-smoothed surfaces in canyons (Pl. 5, fig. 2), range in dimension from fractions of an inch to about 1 foot. The fragments and the matrix are petrographically alike and in many places are barely distinguishable from each other. Many thin sections of volcanic rocks, chosen from widely scattered areas in the Soda Mountains, reveal a surprising petrographic uniformity and consistent mineralogic and textural range from less altered to more altered rocks depending upon proximity to intrusions. The Soda Mountain volcanic rocks were originally andesine (?) andesites and subordinate dacites with pilotaxitic texture, euhedral andesine (?) phenocrysts ½–3 mm across, and low content of ferromagnesian minerals.

All the volcanic rocks have undergone low-grade thermal metamorphism, and nearly

appear to have reached equilibrium. Only rarely has the primary andesine (?) escaped conversion into albite-oligoclase (An_{8-12}), and the hornblende and biotite into chlorite, epidote, actinolite, and sericite. The least metamorphosed rocks display feldspars clouded by sericite, calcite (?), and kaolin (?). The mafic minerals are largely converted to chlorite, but quartz is barely affected, and epidote and actinolite have not formed. The rocks showing maximum alteration (those nearest plutonic intrusions and those in breccia zones) exhibit destruction of primary minerals and texture with the concurrent formation of disseminated albite, epidote, sericite, actinolite, and rarely calcite. Epidote, the most obvious alteration product, gives a greenish tint to most of the volcanic rocks. The reconstitution of the original minerals was a hydrothermal effect of the Late Mesozoic plutonic invasion. Metamorphism involved essentially a redistribution of calcium, producing albite (albitization) and epidote (epidotization). The anorthite content of the original plagioclase was released, redistributed by solutions, and concentrated chiefly in the form of epidote. Nearly all the feldspars are now albite, choked with cloudy alteration minerals. This suggests removal of calcium and accommodation of the accompanying decrease in volume. The occurrence of epidote widely disseminated in the volcanic rocks and commonly concentrated in breccia zones, fractures, and veins supplies abundant evidence for solution activity. Other less widespread alterations are chloritization of the ferromagnesian minerals, sericitization, and local silicification.

The heterogeneous clastic rocks of the Soda Mountain formation range from coarse-grained and conglomeratic, poorly sorted volcanic sandstone to medium- and fine-grained quartzite. The quartzite is variously contaminated with pyroclastic debris. Generally the quartz sandstone is recrystallized to quartzite close to granitic rocks (S-6), although there are notable exceptions (R-8). The red, yellow, white, brown, and gray colors of the sandstone are extremely variable laterally and vertically, depending more or less on the relative abundance of volcanic and quartz clasts (Pl. 5, fig. 4). Cross-bedding of probable fluviatile and possible eolian origin is common and in some places reaches amplitudes of 5 feet or more. Cross-bed measurements indicate that the current flowed mainly northeastward, which indicates a southwestward source highland. Discontinuous and irregular bedding within the sandstone bodies is everywhere characteristic. The largest preserved lenses of sandstone are at least 500 feet long and 300 feet in maximum thickness. They are visible from the highway at the southern end of Highway Spur. On Spectre Spur, the bedding is thinner and more heterogeneous, principally because of variable pyroclastic content.

The pyroclastic constituents in the Soda Mountain formation consist of welded tuffs and tuffaceous impurities in the sandstones and flow breccias. Welded tuff is locally well developed (L-6), and it grades into typical flow breccia. Some of the volcanic sandstone is rich in lapilli and ash. Originally, pyroclastic material may have been much greater in volume. Erosion contemporaneous with deposition may have winnowed out ashy sediments and left behind volcanic and quartz clasts.

AGE AND CORRELATION: The unfossiliferous Soda Mountain formation disconformably overlies the fossiliferous Lower Triassic beds. The time hiatus between the two units is probably short, as indicated by the gradual change in sedimentary rocks upward into similar sedimentary rocks interbedded with the basal flow breccias. Early Triassic fossils occur about 850 feet below the base of the Soda Mountain formation. No rocks are known to overlie the formation stratigraphically in the mapped area or elsewhere in the region. Cretaceous plutonic rocks intrude the formation in many places. Thus on the strength of field relations, the age of the Soda Mountain formation is post-Early Triassic and pre-Cretaceous.

The red and yellow cross-bedded sandstones of the Soda Mountain formation cropping out on the southern part of Highway Spur (T, U-13, 14) bear convincing lithologic resemblance to the westernmost exposure of Jurassic (?) Aztec sandstone mapped by Hewett (1956, p. 48) at Mountain Pass. This striking similarity between the two sandstones has been noted independently by Hewett (1953, personal communication), by Noble (1954, personal communication), and by the writer. Petrographic correspondence has also been noted between the purple andesites and dacites of the Soda Mountain formation and the dacite flow breccia which disconformably overlies the Aztec sandstone at Mountain Pass. Hence, the correlation of the Soda Mountain formation with Aztec sandstone and associated volcanic rocks in the Mountain Pass area seems to be a very sound one. The Aztec sandstone is determined to be a westward extension of the Lower

Jurassic (?) Navajo sandstone of the Colorado Plateau region (Baker *et al.*, 1936, p. 20).

In summary, the Soda Mountain formation can be assigned rather safely a Triassic-Jurassic age on the basis of field relations in the Soda Mountains and lithologic correlation with Jurassic (?) rocks eastward.

Several volcanic units elsewhere in the Mojave and southern Basin Range provinces are tentatively dated as Triassic-Jurassic and may be lithologic analogues of the Soda Mountain formation or at least may belong to the same general period of volcanic activity and sedimentation. Hewett (1956, p. 48–49) mapped a dacite flow breccia, to which he assigned no formational name, southwest of Old Dad Mountain in the southwest corner of the Ivanpah quadrangle. It is almost certainly the same unit as the flow breccia of the Soda Mountain formation on Zzyzx Hill (Hewett, 1953, personal communication). Hewett correlates this flow breccia with the dacite, the last of the Mesozoic succession, overlying Aztec sandstone at Mountain Pass.

In the southern Panamint Range is preserved at least 4500 feet of andesite breccia, designated as the Lower (?) Triassic Warm Spring formation (Johnson, 1957, p. 385–387). Brief field observation indicates that this correlates lithologically with the andesite of the Soda Mountain formation. The Triassic sedimentary and volcanic rocks in the Inyo Range (Knopf and Kirk, 1918, p. 47–48, 58–60) lithologically resemble the Soda Mountain formation. Southwest of the Soda Mountains possible correlatives of the Soda Mountain formation are the Ord Mountain group in the Ord Mountains (Gardner, 1940, p. 270), the Sidewinder volcanic series in the Barstow quadrangle (Bowen, 1954, p. 52), the Amargo group northwest of Barstow (Gale, 1946, p. 358), and the Santiago Peak volcanics in the Santa Ana Mountains (Larsen, 1948, p. 22–27).

The extrusive volcanic rocks and interleaved clastic rocks in the Soda Mountains are assigned a new formational name, because they are a unique and widespread mappable unit. Extending the Navajo or Aztec formation to apply to the sandstones within the formation is not acceptable in view of the intricate interfingering of many volcanic rocks and sedimentary tongues (Fig. 2). This differs from the relatively uniform sandstone and the lack of volcanic rocks in the Aztec and Navajo formations. The application of established names of possibly correlative volcanic rocks in the region, such as Ord Mountain, Sidewinder, and Warm Springs, is not permissible because they see to lack significant sandstone beds, and the do not possess lithologic features on which specific correlation can be extended with con fidence.

The intermediate position of the Soda Mou tain formation between the clastic sedimentar rocks eastward and the volcanic accumulation westward is a unique feature.

Relations of the Triassic-Jurassic Rocks

Lower Triassic calcareous and shaly sedi mentary rocks, generally resembling the Moenkopi formation of southern Nevada, are exposed in a northwest-southeast line formed by the Inyo Range, Panamint Range, Soda Mountains, and Providence Mountains. Though the region between this line and southern Nevada is now devoid of Lower Triassic sedimentary rocks, they probably were de posited as a continuous blanket across the region and have since been eroded. Southwest of the northwest-trending line through the Soda Mountains are rare occurrences of rocks questionably dated as Early Triassic. They consist of great thicknesses of clastic debris in a moderate to advanced state of regional meta morphism. This marked difference in lithology suggests that the northwest-trending line through the Soda Mountains closely delineates a regionally significant division in Early Triassic time between relatively thin and uniform sedimentation northeastward and thick geosynclinal accumulation southwestward. In the Mojave province this division roughly parallels the eastern border of Schuchert's (1923, p. 225) Pacific geosyncline.

In the Soda Mountains the upward transition of Lower Triassic calcareous and shaly sediments into sandstone and volcanic flow breccia, the basal portions of which are presumably Middle or Upper Triassic, appear roughly analogous to the record in the southern Panamint Range (Johnson, 1957), the Inyo Range (Knopf and Kirk, 1918), and in west central Nevada (Muller and Ferguson, 1936). Unlike these areas, however, the succession in the Soda Mountains attests to continued volcanic activity and intermittent continental sedimentation from Mid-Triassic through Early Jurassic. During this span of time, vol canic material accumulated to the southwest, sandstone was deposited to the northeast, and both lithologies interfingered in the Soda Mountains area (Fig. 2). Therefore, the Soda Mountains again occupied an intermedia

position between two distinctly different environments generally during Middle Triassic to Middle Jurassic time.

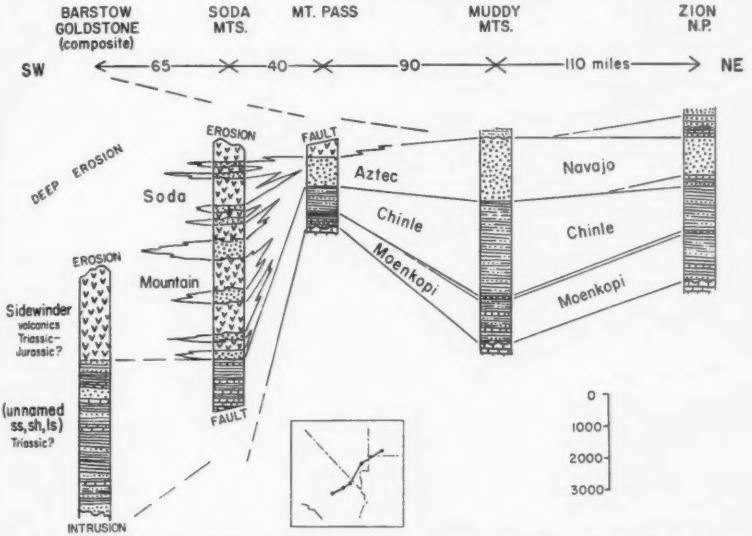

FIGURE 2.—TRIASSIC-JURASSIC SECTIONS FROM BARSTOW, CALIFORNIA, TO ZION NATIONAL PARK, UTAH
Barstow-Goldstone: Bowen (1954), McCulloh (*in* Hewett, 1955, p. 381); Soda Mts.: this report; Mt. Pass: Hewett (1956); Muddy Mts.: Longwell (1928); Zion National Park: Gregory (1950)

INTRUSIVE IGNEOUS ROCKS

Pre-Tertiary Plutonic Rocks in the Eastern Area

The area in the Soda Mountains east of the Soda-Avawatz fault zone is referred to as the eastern area, and that west of the fault zone as the western area.

FIELD RELATIONS: A large part of the eastern area is underlain by a complex of closely allied crystalline plutonic rocks. They are generally unlike the plutonic rocks occurring in the western area. They were divided into six major formations for the purpose of ascertaining areal, petrographic, and structural relations. As a rule, the contacts between the units are vague and transitional; the contact zones range in width from about 50 to 500 feet, and they are vertical to subvertical.

Granodiorite[2] and quartz diorite are most widespread. Granite occurs to a lesser extent in irregular lens-shaped pods which are locally crudely aligned. A basic complex is associated with intruded carbonate rocks. Migmatite and porphyritic granodiorite are subordinate in volume and are restricted to Lakeshore Hill.

PETROGRAPHY: On the basis of identification with the hand lens, coupled with examination of several thin sections, the diversified assemblage of plutonic rocks was differentiated into microcline granite, granodiorite, quartz diorite, porphyritic granodiorite, migmatite, and basic complex. Thorough mixing of these rocks is so widespread that it was necessary to group them into several areas, each dominated by one unit and including a variable but minor amount of other rock types.

The basic complex is probably the oldest of the plutonic series, but it may be merely a border phase substantially coeval with the more acidic rocks. It is areally associated with the pre-Mesozoic limestone and dolomite formation (N, O-12, 13; D-12; Pl. 4, fig. 1), which

[2] In naming the various plutonic igneous rocks, the classification offered by Wahlstrom (1947) has been followed. Granite, quartz monzonite, granodiorite, and quartz diorite contain more than 5 per cent quartz. The ratios of K,Na feldspar to Na,Ca feldspar in these rocks are as follows: in granite, greater than 5:3· in quartz monzonite, 5:3–1:1; in granodiorite, 1:1–3:5; and in quartz diorite, less than 3:5. Diorite contains less than 5 per cent quartz and K,Na feldspar and Na,Ca feldspar (oligoclase and andesine) in ratio less than 3:5. Adamellite includes quartz monzonite and granodiorite.

suggests that it represents an originally acidic magma contaminated by contact with carbonate sediments. The basic complex comprises irregular masses of slightly gneissic to massive and directionless diorite, gabbro, and hornblende-epidote rock. It is locally traversed by quartz or silexite dikes and migmatitically replaced by acidic material.

The quartz diorite and granodiorite are intimately transitional and very difficult to separate in the field. The type area of the quartz diorite phase is Dolomite Mountain where the rock is dark gray, medium-grained, uniform, and massive and directionless. Microscopically, the rock has an irregular texture which appears somewhat crystalloblastic. It contains poikiloblastic hornblende and biotite and intergranular quartz and microcline. Andesine (An_{34-38}) makes up more than half of the volume. It is followed by about equal amounts of microcline, quartz, and biotite. In comparison with the quartz diorite, the granodiorite is light gray, contains more potassium feldspar and quartz and less plagioclase, and is somewhat more typically igneous in texture. The over-all petrographic features of the granodiorite formation are intermediate between those of the quartz diorite and granite formations.

The microcline granite is generally a more distinctive phase than the quartz diorite and granodiorite. It is white to very light gray, medium- to coarse-grained, massive, and essentially uniform. The texture is typically hypautomorphic granular. About 70 per cent of the rock is microcline without phenocrystic habit, 20 per cent quartz, and 5 per cent oligoclase (An_{25}). Sphene and epidote are trace minerals.

The porphyritic granodiorite occurs only on Lakeshore Hill. It is medium to dark gray and contains unoriented anhedral to euhedral crystals, up to 10 mm in length, of pink potassium feldspar set in a dark fine-grained groundmass. The borders of feldspar crystals are more or less sutured, and inclusions of dark minerals are conspicuous. These features suggest that the crystals are porphyroblasts rather than phenocrysts.

Quartz diorite, granodiorite, and granite are concentrated locally in the Lakeshore Hill area, forming a complex of units impossible to map individually on the scale used (1:13,000). They are logically grouped under the term migmatite as used in a purely descriptive sense. The following features distinguish the migmatite formation: (1) Mixtures of several types occur in areas of a few square feet or locally of much larger scale. (2) The migmatite appears to lack consistent internal structure or orderly distribution of rock types. (3) Contacts range from sharp to transitional. (4) Both metamorphic and igneous textures appear in the complex. (5) Structural interrelations suggest that the light-colored acidic portions are the last to form.

In the complex of pre-Tertiary plutonic rock as a whole, intrusive relationships shown by inclusions of the xenolithic type and crosscutting dikes suggest a progressive invasion of increasingly siliceous rocks. The highly irregular and gradual mineralogic and textural transition between the units, however, suggests ill-defined differentiation from a single intrusion, or possibly it indicates large-scale metasomatism. The genesis of this plutonic complex remains one of the fundamental petrologic problems in the region.

AGE AND CORRELATION: The close alliance of the various phases of the pre-Tertiary plutonic complex petrographically and spatially strongly suggests close alliance in time. In the surrounding region plutonic activity reigned at two widely separate periods—the Early Precambrian and Late Jurassic to Early Tertiary (McCulloh, 1954, p. 20–22).

As a group these rocks invade Lower Precambrian (?) gneiss, Upper Precambrian (?) and Lower Cambrian (?) metasedimentary rocks, and pre-Mesozoic (Middle Paleozoic?) limestone and dolomite. The quartz diorite phase underlies the Lower Permian Bird Spring formation on Baker Hill in probable intrusive relationship, but the critical contact is obscured by talus. In the Moonshine area, the basic complex phase (which appears to be the oldest in the plutonic series) is intruded by Cretaceous quartz monzonite. In summary, by integrating the field relations within the Soda Mountains, the complex may tentatively be considered post-Lower Permian; it is probably Upper Mesozoic. Serious doubt arises, however, when considering other plutonic complexes in the region which in part resemble the complex in the Soda Mountains, for they are usually regarded as Early Precambrian.

The Halloran complex (Hewett, 1956, p. 22; Miller, 1946, p. 499), which covers a wide area east of the Soda Mountains and is considered Lower Precambrian largely on the basis of metamorphism, bears partial petrographic resemblance to the complex in the Soda Mountains. Some of the crosscutting granitic dikes within the Halloran complex may be Upper Mesozoic.

Brief field examination prompted Wright (1954, personal communication) to regard the slightly foliated basic complex phase of the plutonic series as possibly correlative with metamorphic rocks of Early Precambrian (?) age in the Silver Lake Talc area (Wright, 1954, p. 19).

The Lower Precambrian granitic and metamorphic rocks in the eastern Mojave Desert are characterized by foliation; only a few masses of syenite of Precambrian age are unfoliated (Hewett, 1955, personal communication). In contrast to these older rocks, most of the Upper Mesozoic plutonic rocks are massive and directionless. The unfoliated or massive and directionless nature of the plutonic complex in the Soda Mountains, therefore, strongly suggests a Late Mesozoic age.

In conclusion, since the rocks of the plutonic complex are not in visible contact with rocks of known geologic age and cannot be definitely correlated with them, their age remains in doubt. However, available evidence weighs rather heavily in favor of a Late Mesozoic age.

Upper Mesozoic Plutonic Rocks in the Western Area

FIELD RELATIONS: A closely related series of plutonic rocks occurs almost entirely west of the Soda-Avawatz fault zone and in a large unmapped area of the Soda Mountains farther southwest. They have passively intruded Paleozoic and Mesozoic formations and have effected widespread thermal metamorphism which involved tactitization of the carbonate rocks, conversion of argillaceous rocks to hornfels, and hydrothermal alteration of the volcanic flow breccia.

The four petrographic types represented in the series are, in order of decreasing age: quartz diorite, adamellite, granite, and altered granitic rocks. Of these, quartz diorite and adamellite are by far the predominant types. The contacts between different plutonic rocks are almost everywhere steeply inclined and are either sharp or transitional; but the contacts of the plutonic rocks with the country rocks are variably inclined and everywhere abrupt. The over-all trends of the major contacts are roughly in accord with the pre-intrusion fault pattern (O-5, 6; M-7). This implies structural control of magmatic invasion. The phases of this series are not intimately mixed on a small scale as they are in the plutonic complex in the eastern area; instead, each phase occurs rather uniformly over relatively large areas. The quartz diorite and adamellite mix only in their contact zone, but the granite occurs in three long sharply defined northwest-trending dikes near and parallel to the Soda-Avawatz fault zone. This indicates a genetic relationship between the intrusion of Upper Mesozoic plutonic rocks and regional faulting. The highly altered granitic rocks are essentially restricted and are related to contact metamorphism and mineralization attending intrusion around the Blue Bell Mine area.

PETROGRAPHY: Quartz diorite and minor amounts of diorite constitute a relatively heterogeneous group of dark-gray, fine- to medium-grained, massive and directionless, and in part slightly migmatitic rocks. The diorite is fine-grained, dark, and generally faintly crisscrossed by thin veins of granitic material. Some portions of the quartz diorite grade into granodiorite which is coarser-grained and lighter. Under the microscope, this plutonic phase reveals irregular alteration and recrystallization of the primary allotriomorphic-granular texture and development of epidote, sericite, and chlorite in cloudy disseminations and in fractures. The original minerals are largely obscured by alteration.

The adamellite, which correlates petrographically with the Teutonia quartz monzonite of Hewett (1956, p. 61–65) in regions eastward and southward, is medium-grained, massive and directionless, and pink because of pink orthoclase. Two local varieties occur within this unit. One is coarse-grained white adamellite occurring in the western part of the Soda Mountains (Q-4, 5). The other is medium-grained and locally porphyritic and has a fine-grained groundmass; it occurs sporadically south of Spectre Spur (O, P-5) and at the north end of Granite Ridge. These two varieties grade imperceptibly into the typical adamellite which is hypidiomorphic granular and contains nearly equal amounts of orthoclase, sodic oligoclase, and quartz with less than 10 per cent hornblende, biotite, sphene, epidote, and magnetite.

Most of the granite is coarse-grained, light, and irregular in texture. Very coarse pegmatitic phases do not occur, but a white aplitic phase is locally prominent. In some places, particularly the north end of Granite Ridge, orthoclase develops pink euhedral phenocrysts which resemble those in the felsite porphyry dikes. No dikes are seen originating from the granite, however. The texture of this granite phase is hypidiomorphic granular, and the mode is orthoclase 50 per cent, microcline 20 per cent, and quartz, albite, and oligoclase each 10 per

cent. Penninite (after biotite) and magnetite usually constitute less than 1 per cent.

The altered granitic rocks form a heterogeneous and indefinite marginal phase that is confined to the Blue Bell Mine area where they are intimately associated with pendants of contact-metamorphosed limestone, hornfels, and volcanic rocks. Their colors are splotchy mixtures of white, gray, brown, red, and green. Orthomagmatic microcline, orthoclase, and plagioclase were brecciated and later healed by crystallization of quartz and epidote. The altered granitic rocks appear to have originated by brecciation of quartz dioritic rocks, probably because of movement of subjacent magma, which was closely followed by silicification and epidotization. The presence of lead, silver, and copper mineralization is undoubtedly related to these late magmatic effects.

The presence of xenoliths and crosscutting dikes in contact zones between the three plutonic phases conclusively demonstrates that the quartz diorite is followed by adamellite and finally by granite in intrusive sequence. Petrographic transition in places along the contact between quartz diorite and adamellite suggests that they are nearly related in genesis and time. However, the relative distribution of the three phases is completely unrelated to differences in their composition or to the composition of the invaded rocks. This suggests that they are separate intrusions rather than the result of the differential cooling, crystallization, and contamination of one intrusion.

AGE AND CORRELATION: In the Soda Mountains the crystalline rocks intrude the Triassic-Jurassic Soda Mountain formation and are intruded by Upper Mesozoic or Lower Tertiary dikes. Petrographically, the adamellite phase appears nearly identical to the Upper Mesozoic or Lower Tertiary Teutonia quartz monzonite which underlies large areas in the southwestern half of the Ivanpah quadrangle and crops out several miles south of the Soda Mountains (Hewett, 1955, personal communication).

Field evidence is corroborated by a zircon age determination of 96 million years or Cretaceous age (Larsen *et al.*, 1958, p. 50, sample G-24M). The analyzed sample was gathered a short distance south of the highway on Zzyzx Hill (Y-12). It is gray microperthitic quartz monzonite. It has the same field relations and general petrographic features as the Teutonia quartz monzonite, and it appears to fall within the range of safe correlation with the Upper Mesozoic plutonic assemblage 5 miles to the northwest in the Soda Mountains.

By the same age-determination method, quartz monzonite in the northern Providence Mountains revealed an age of 94 million years (Larsen *et al.*, 1958, p. 50, sample G-21). This age and the age determined for rocks from Zzyzx Hill are in fair agreement with an average age of 110 ± 13 million years obtained for rocks from the Southern California batholith and 102 ± 11 million years for Sierra Nevada rocks (Larsen *et al.*, 1958, p. 48–50).

In the Mojave Desert, the over-all similarity of widespread Upper Mesozoic quartz monzonite, variously named by different workers, is pointed out by McCulloh (1954, p. 21). Undoubtedly, the plutonic rocks west of the Soda-Avawatz fault zone in the Soda Mountains fall into this same regional type.

Upper Mesozoic or Lower Tertiary Dike Rocks

FIELD RELATIONS: The pre-Pliocene rocks of the Soda Mountains are variously intruded by innumerable hypabyssal dikes, plugs, and irregular masses of diabase and felsite. Only the largest masses were mapped. In the western area the two types form prominent vertical to south-dipping dikes trending N. 60°–70°W., which range in width from 1 to 100 feet and in length from about 100 feet to 2 miles (Pl. 6, fig. 1). The dikes tend somewhat to avoid the areas of more massive and competent rock, such as the granite on Granite Ridge and the quartzite roof pendant west of the Blue Bell Mine area (S-5, 6). However, their over-all trend is consistent through all the rocks without deviating, converging, or radiating patterns. This suggests that the source magma was not in the area or that it lay at considerable depth. The absence of vesicles implies that the rocks were intruded at depth.

There is some variation in the abundance and distribution of the dike rocks. Diabase is generally more abundant. Large pluglike masses of felsite are concentrated in the faulted-block complex on the west side of Spectre Spur (M-5). Around the Blue Bell Mine area, the dikes are so abundant that they constitute nearly half of the exposed rocks. The total volume of hypabyssal intrusive rocks is estimated to equal about one-fifth of the exposed volume of pre-Pliocene rocks in the area west of the Soda-Avawatz fault zone.

The dike intrusions in the eastern area differ greatly from those in the western area. Diabase is again the predominant type, and felsite is almost entirely restricted to Baker Hill. The intrusions are small, irregular, and lacking in

obvious regional or local orientation. It is not certain whether this diabase is the same age or in any way genetically related to the diabase west of the fault zone. The porphyritic types so common in the western area are notably absent in the eastern area.

PETROGRAPHY: The diabase is dark gray, very fine-grained, and uniform. A few glassy borders occur, and joints and fractures are filled with epidote. Under the microscope the rock appears finely recrystallized and clouded throughout by epidote, sericite, and indefinite alteration minerals. A porphyritic variety, usually occurring in larger intrusions, contains euhedral andesine-labradorite (An_{48-58}) phenocrysts up to half an inch in length.

The felsite is light reddish tan to light gray, aphanitic to very fine-grained, massive, and uniform. The felsite porphyry variety is restricted to large dikes and plugs and is characterized by pink euhedral orthoclase phenocrysts, many of which are set in a light-purple aphanitic matrix. Characteristically these felsites display granophyric and spherulitic intergrowths of orthoclase and quartz and a general clouding by indefinite alteration minerals.

AGE: Crosscutting dikes are exceedingly rare, and inclusions of one dike rock in another are apparently nonexistent. In two places, however (R-5), diabase is cut by through-going felsite dikes, which establishes an earlier age for the diabase.

Field relations demonstrate that the dikes in the western area postdate the granite, which is the last of the Cretaceous intrusive succession, and antedate the lower Pliocene Avawatz formation. Since the dikes are altered in a manner similar to other rocks in the area, and since alteration is generally believed to coincide with the cooling or end stages of plutonism, the dikes probably were emplaced shortly after consolidation of the granitic magma. Typical Tertiary volcanic rocks are not altered or epidotized on a regional scale in the Mojave province (Hewett, 1955, personal communication). Hence, the age of the dikes is probably Late Cretaceous or Early Tertiary.

Relations of the Plutonic and Dike Rocks

The plutonic series in the eastern area, referred to as the eastern plutonic rocks, and the series in the western area, the western plutonic rocks, differ as follows:

(1) Field relations. Generally the eastern plutonic rocks are in contact with moderately to highly metamorphosed Precambrian and Lower Paleozoic sedimentary rocks, whereas the western plutonic rocks are in contact with less metamorphosed Upper Paleozoic and Mesozoic rocks. The series mix in one place—the Moonshine area.

(2) Petrographic types and association. The eastern plutonic complex involves a wider variety of types than the western group. They are more intimately mixed and show more metamorphic characters.

(3) Shapes of intrusions. The boundaries of the eastern plutonic rocks individually are rather vague and irregular. The western plutonic rocks usually show boundary trends that suggest some tectonic control of intrusion.

(4) Dike-rock assemblage. The eastern plutonic rocks contain small pipes and unsystematic dikes of diabasic rocks, whereas the western plutonic rocks are cut by innumerable systematic N. 70° W. dikes of diabase and felsite.

In spite of these basic differences between the eastern and western plutonic suites, the field evidence collectively implies that they are both essentially a result of Late Mesozoic plutonic activity that profoundly affected the Mojave region.

Cenozoic Sedimentary Rocks

Lower Pliocene Avawatz Formation

FIELD RELATIONS: The Avawatz formation in the Soda Mountains includes several thousand feet of locally derived, coarse, continental, clastic sediments, which have petrologic features of modern alluvial and talus accumulations (Trowbridge, 1911) or fanglomerates (Lawson, 1913). They occur unconformably overlying and faulted against the older rocks and unconformably underlying Quaternary alluvium; they are everywhere tilted and faulted. The greatest exposed section occurs within the Soda-Avawatz fault zone east of Granite Ridge (Pl. 2). Several thousand feet of beds has been eroded from the top of the anticline on Highway Spur (U-13). Limited outcrops on Target Flat (J-9) and in the long fault basin west of Spectre Spur suggest that the beds continue under a thin alluvial veneer northward to the southern end of the Avawatz Mountains where the Avawatz formation was originally described by Henshaw (1939, p. 4–9).

The Avawatz formation in the Soda Mountains has been divided into three members on the basis of grain size: a lower boulder fanglomerate member at least 3200 feet thick; a middle member of sandstone, pebble lenticles, and subordinate tuff, totaling about 1000 feet in thickness; and an upper member of pebbly debris at least 1100 feet thick. Nowhere are these units in unbroken succession. The least faulted and most nearly complete section, though not necessarily the most typical, occurs in a southwest-dipping monocline southwest of Highway Spur and north of the highway.

The combined effects of faulting, which is commonly parallel or at low angles to the strike of the bedding, and rather abrupt change in lithology of each member render the study of the stratigraphy and the original extent of the Avawatz formation very difficult. The beds are partially eroded from the crest of the anticline on Highway Spur (S-12), and here they rest on terrain of moderate relief (at least 200 feet of elevation difference in a quarter of a square mile). The composition, angularity, and size of the clasts collectively prove that the beds were formed from erosion of adjacent uplands.

LITHOLOGY OF THE THREE MEMBERS: The lower member is fanglomerate rich in angular to subrounded pebbles and boulders derived from mostly unaltered rocks of the Soda Mountain formation and is consequently reddish. It also contains substantial amounts of all other rock types in the Soda Mountains occurring west of the West fault, but few rock types occurring east of the East fault. Bedding is usually lacking, although at several places it is faintly expressed by boulder orientation and local sorting. Generally this fanglomerate member is unsorted. At places huge angular blocks measuring several feet in diameter occur isolated in the relatively finer debris which ranges in size from the finest particles to clasts 1 foot in maximum dimension. There is no matrix of clay or mud; the interstices between the larger clasts are filled with smaller clasts. The degree of cementing varies widely, depending upon the amount of limestone clasts in the section. Some portions are no more consolidated than modern alluvium. A few lenses of monolithologic purple andesite breccia occur closely associated with limestone breccia (discussed below). The clasts range from sand size to blocks several feet in diameter. Except for association with fanglomeratic sedimentary rocks, these sedimentary andesite breccias would be practically indistinguishable from volcanic flow breccias.

The middle member of the Avawatz formation in the Soda Mountains is a heterogeneous accumulation of coarse arkose, fine to coarse fanglomerate or gravel, and subordinate sandy tuff. The gravel is rich in granitic rocks, but it contains clasts of all other rock types from both sides of the Soda-Avawatz fault zone. In contrast to the other members, stratification is well developed at some places. Sandstone beds up to 50 feet thick and several hundred feet long are common. Rather indefinite lens and pocket stratification is typical in many places. This light-brown member, which has

PLATE 6.—PANORAMIC VIEWS OF PARTS OF THE SODA MOUNTAINS

FIGURE 1.—View northward of Upper Mesozoic granitic rocks in the western part of the area mapped (N-Q—4-8). Upper Mesozoic or Lower Tertiary diabase and felsite dikes form prominent ridges and streaks. In the left background is the summit of Spectre Spur composed of Bird Spring limestone thrust mass.

FIGURE 2.—View eastward of the west side of Spectre Spur. Mls—Mississippian-Pennsylvanian(?) limestone, Msv—Soda Mountain formation, Pbs—Bird Spring limestone, Ti—felsite porphyry. Lines mark major east-dipping thrust faults. Far West fault extends along base of mountain.

PLATE 7.—LATE MESOZOIC THRUST FAULTS

FIGURE 1.—Oblique air photograph of Spectre Spur view northeastward. Mls—Mississippian-Pennsylvanian(?) limestone, Mss—sandstone in Soda Mountain formation, Msv—andesite in Soda Mountain formation, Pbs—Bird Spring limestone. The entire block of Paleozoic limestone was thrust over the Mesozoic Soda Mountain formation and relatively dropped along major vertical faults (inked lines to left and to right). Sinuous line is uppermost major low-angle thrust fault.

FIGURE 2.—View northeastward along the south side of Spectre-Spur (M-6). Intensely deformed Bird Spring limestone is in thrust contact over Upper Paleozoic limestone and hornfels. White streaks are recrystallized calcite in fracture zones. Ink line marks position of thrust fault. Scale is about 600 feet from top to bottom.

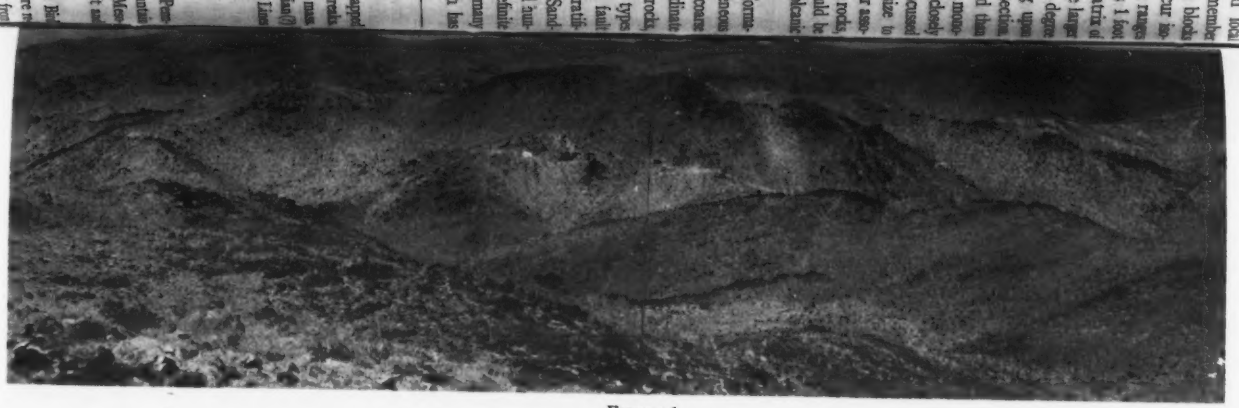

FIGURE 1

FIGURE 2

PANORAMIC VIEWS OF PARTS OF THE SODA MOUNTAINS

FIGURE 1

FIGURE 2

LATE MESOZOIC THRUST FAULTS

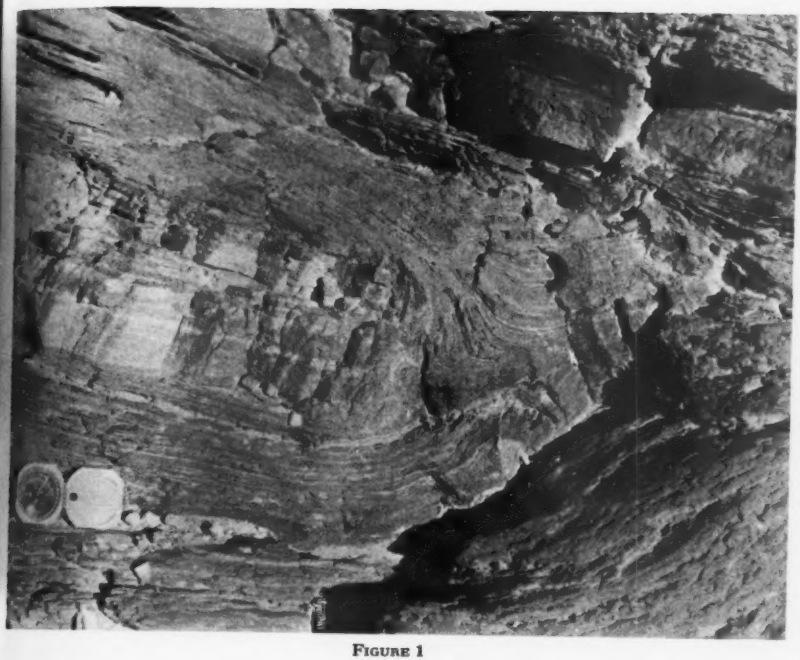

FIGURE 1

FIGURE 2

FIGURE 3

LIMESTONES IN THRUST ZONES

FIGURE 2

FIGURE 4

FIGURE 1

FIGURE 3

MONOLITHOLOGIC LIMESTONE BRECCIA

prominent sandstone layers, usually contrasts markedly with the reddish lower member.

In rather indefinite contact with the middle member, the upper member emerges as a light-brown fine-gravel fanglomerate. It contains angular fragments of many rock types. Normally the clast size does not exceed 3 inches, but in places it exceeds 2 feet. Cementing is weak, and clay matrix is very scanty.

AGE AND CORRELATION: This fanglomeratic succession in the Soda Mountains is correlated on the basis of lithology and areal relations with the Avawatz formation at its type locality at the southern end of the Avawatz Mountains. Henshaw identified vertebrate fossil material of early Pliocene age near the top of the Avawatz formation and offers his opinion (1939, p. 9) that the lower part was deposited near the end of late Miocene time and the uppermost part in early Pliocene. The Avawatz faunas are later than Barstow and "perhaps slightly pre-Ricardo in age" (1939, p. 16).

Monolithologic Limestone Breccia

DESCRIPTION: One of the most amazing rocks in the Soda Mountains, as in some other parts of the region, is the monolithologic limestone breccia in the Avawatz formation. The breccia forms isolated masses the size of an automobile and irregular tabular bodies 10–100 feet thick and up to 2000 feet long (Pl. 2; Pl. 9, fig. 4). One bed occurring on the east side of Highway Spur averages about 30 feet thick and continues for 2 miles. The breccias are essentially monolithologic and are made up of angular to subrounded clasts of white and gray limestone of the type that constitutes the Upper Paleozoic limestone formations. The masses are strongly self-cemented, and they crop out as resistant ridges and hillocks. They occur scattered through the lower and middle members of the Avawatz formation within the Soda-Avawatz fault zone. Field evidence indicates that the breccias are inextricably involved with the sedimentational processes that built up the Avawatz formation, instead of being tectonically placed in the section.

The lower limit of the breccia beds is usually sharp and smooth and abruptly in contact with the heterogeneous clasts of the fanglomerate. Shearing and granulation of either rock at the contact is usually, though not everywhere, absent. In a few places the base is indefinite, and the normal fanglomerate grades upward into limestone-rich beds. The limestone breccia locally rests directly on bedrock of meta-andesite of the Soda Mountain formation (Q, R-11). In such cases, the contact between the two rocks shows both shearing and normal sedimentary relations. The upper surface of the breccia beds is nearly as sharp as the lower but is less smooth. The margins usually wedge out into heterogeneous fanglomerate, though in a few places they terminate abruptly (P-11).

The clasts constituting the monolithologic limestone beds range from ordinary gravel to the size of a medium-sized house. Simple clasts consisting of single fragments of limestone usually uniform, but in a few places internally bedded, are generally small and widespread. Compound clasts composed of fragments of many different kinds of limestone cemented together mainly as tectonic breccia

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PLATE 8.—LIMESTONES IN THRUST ZONES

FIGURE 1.—Sheared Lower Cambrian(?) limestone in thrust zone which incorporates a block of argillite torn loose from the autochthon. Quartzite Hills (H-13).

FIGURE 2.—Brecciated Lower Cambrian(?) limestone in thrust contact over Precambrian(?) metasediments. Quartzite Hills (I-11).

FIGURE 3.—Tectonic limestone breccia in a thrust zone in the Bird Spring formation along the highway on Baker Hill. It resembles sedimentary limestone breccia.

PLATE 9.—MONOLITHOLOGIC LIMESTONE BRECCIA

FIGURE 1.—Part of a single clast of tectonic breccia in the sedimentary limestone breccia.

FIGURE 2.—Sedimentary limestone breccia composed of clasts of relatively uniform limestone. This breccia is practically indistinguishable from tectonic breccia.

FIGURE 3.—View northeastward of a long fault sliver of monolithologic limestone breccia in the Soda-Avawatz fault zone (N-8, 9). Meta-andesite of the Soda Mountain formation is in the foreground.

FIGURE 4.—View northeastward of a lens of monolithologic limestone breccia in lower Pliocene Avawatz formation (P-11). Strata dip eastward. Silver Lake playa is in background.

before they were moved into place are of all sizes and widespread. Aggregates of clasts cemented together after they were deposited, or pseudoclasts, resemble the compound clasts. The clasts are cemented together by calcium carbonate, which incompletely fills the interstices. Clay and other fine-grained materials that are usually associated with slope deposits typical of mudflow are lacking.

Apparent gradation between compound clasts and pseudoclasts is common. In some cases it is impossible to tell whether a clast represents a single giant block of tectonic breccia or a chaotic and sheared (as a result of landsliding) complex of well-cemented sedimentary blocks. Clasts of tectonic breccia display predepositional cementing by calcium carbonate and chert-derived silica (Pl. 9, fig. 1). The cementing is so strong that transportation of the clasts did not entirely crumble or dissociate them.

Three genetically distinct types of shears are present in the breccia masses: (1) shears that transect the whole Avawatz formation, including the monolithologic breccias; formed during early Pliocene and later tectonic activity; (2) shears that are confined to the breccia beds and transect clasts but deviate around some large ones; formed mostly by landsliding into place; (3) shears restricted to clasts of tectonic breccia; formed during the complex thrusting of the Nevadan-Laramide orogeny.

The source rocks of the monolithologic breccia are the three Upper Paleozoic units which are locally preserved mostly west of the Soda-Avawatz fault zone. In these units are found beds and pods of tectonic breccia (Pl. 8, fig. 3) which appear identical to masses of sedimentary breccia.

ORIGIN: Monolithologic limestone breccia that appears similar to that in the Soda Mountains, as well as breccia composed solely of other rock types, such as granite, andesite, and gneiss, has been reported in recent years from various localities in southern California and the Basin and Range Province (Henshaw, 1939; Jahns and Wright, 1957). Longwell (1936, p. 1414–1429; 1937, p. 435; 1951) mapped several breccia masses in Miocene and Pliocene fanglomerate, calling them megabreccias (1951), in the Lake Mead area of southern Nevada and western Arizona. He interpreted them as essentially landslide deposits. In northeastern Nevada, Hazzard and Moran (1952) examined in detail some limestone breccia overlying Pliocene (?) lake beds, and they gathered compelling evidence for origin by normal fanglomerate accumulation. The Quaternary (?) Blackhawk breccia (Woodford and Harriss, 1928, p. 279–283) on the northeastern side of the San Bernardino Mountains shows abundant evidence of origin by landsliding, which is related directly or indirectly to low-angle thrust faulting.

In the area near the Soda Mountains, limestone and dolomite breccia occurs in Upper Tertiary fanglomerate and lake beds in the Shadow Mountains (Hewett, 1956, p. 88–90), in the Silurian Hills (Kupfer, 1952, Ph.D. thesis, Yale Univ.), in the Amargosa Valley (Wright, 1954, personal communication), and in the Black Mountains (Noble and Wright, 1954, p. 152). Immediately north of the Soda Mountains, at the southern end of the Avawatz Mountains (A–D—1–6) (Henshaw, 1939, p. 5–7; Jahns and Engel, 1949; 1950), are breccia masses like those in the Soda Mountains, which form an integral part of the Avawatz formation.

There was considerable question over the relative amount and influence of thrusting, landsliding, and normal fanglomerate deposition in the genesis of the monolithologic breccias in the Soda Mountains. When the author first encountered the breccias in the field, the view of origin by thrust faulting was attractive. However, as more evidence accumulated, it reinforced the view of origin by sedimentation and landsliding directly related to faulting.

The limestone breccias of the Avawatz formation in the Soda Mountains afford decisive evidence in favor of a sedimentary-landslide origin. Each mass of breccia is a sedimentary unit interstratified and isolated in fanglomerate and commonly in lithologic gradation with it. No fault along which it could otherwise have been emplaced transects the adjacent fanglomerate. Landsliding, in contrast to other methods of transporting material, allows emplacement of a large mass that in some cases preserves a combination of diagnostic features: angular fragments of all sizes, generally homogeneous lithology of the fragments, some unusually large blocks without the fine-grained or clayey matrix of a mudflow, and some shears restricted to the mass or related to the base of the mass.

The source rocks of the monolithologic breccias in the Soda Mountains are the steeply east-dipping Upper Paleozoic limestones that occur west of the Soda-Avawatz fault zone. Sudden and recurrent uplift on the West fault oversteepened the front of Granite Ridge and Spectre Spur, thereby setting the stage for mass slippage along bedding planes. Abrup

release of large limestone masses carried giant blocks 2 or 3 miles from their source. Finer limestone debris probably moved down at a more leisurely pace and partially mingled with other debris. Sporadic oblique-slip or dip-slip faulting was a necessary prerequisite. Slope instability was further enhanced by the steep east or downslope dip of the source rocks.

These conditions appear fundamentally similar to those set up by Longwell (1951) to explain the origin of landslide breccia near Lake Mead, and by Wright (1955) to explain the origin of the Rainbow Mountain breccia in the Amargosa Valley. In other areas, however, such as the San Bernardino Mountains and the Black Mountains, low-angle thrusting at the source appears necessarily coeval with landsliding.

Upper Tertiary(?) Fanglomerate, Undifferentiated

Two isolated low hills, one north of the Quartzite Hills (F-11), and the other south of Lakeshore Hill (L-12, 13), are underlain by unconsolidated boulder fanglomerate of a composition and field occurrence so distinctly different from that of the Avawatz formation that they are considered a separate formation.

Most of the northern deposit is obscured by sand dunes but appears to lack bedding. The southern reveals bedding and unconformable contact with underlying thrust-faulted pre-Tertiary crystalline rocks. The fanglomerate is almost entirely composed of clasts of plutonic rocks; clasts of limestone and dolomite are rare. All were derived locally from rocks east of the Soda-Avawatz fault zone. No clasts occur from rocks west of the fault zone. The section south of Lakeshore Hill consists of nearly 1000 feet of angular to subrounded granitic clasts set in a sandy and clayey matrix. Most of the clasts are identical to the various plutonic rocks that crop out on South Lakeshore Hill and generally unlike those on Lakeshore Hill. The fanglomerate north of the Quartzite Hills contains clasts that are similar to rocks occurring on Lakeshore Hill and Dolomote Mountain but unlike the rocks in the Quartzite Hills. Obviously this formation reveals an episode of sedimentation when topography differed greatly from its present form.

Correlation with known and dated formations is impossible until more work is carried out in the region. Possibly this formation is a part of the Avawatz formation, though probably it records more recent sedimentation and deformation.

Quaternary Deposits

ALLUVIUM: Alluvium covers large areas surrounding the Soda Mountains. Most of it is coarse, unsorted, and mixed with talus at the base of the mountains, becoming less coarse and roughly sorted at greater distances downslope. Caliche layers are locally developed opposite limestone slopes, such as those west of Spectre Spur (0–3). Quartz sand derived from Prospect Mountain quartzite is segregated into small dunes in the Quartzite Hills. Irregularly scattered on relatively high and flat areas of alluvial surfaces are stretches of desert pavement. At numerous places in the Soda Mountains remnants of older alluvium are still intact low on canyon walls and as capping on low rock surfaces. These are especially well displayed northwest of the Moonshine area (N-11). As indicated by outcrops of bedrock in a few places, alluvium forms merely a veneer over most of Target, Ruin, and Jeep flats. However, at the northwest end of Jeep Flat (P-13) canyons have been cut 60–80 feet into slightly tilted alluvium. This indicates that locally, probably in areas of modern downwarping, alluvium may accumulate to considerable thickness.

PLAYA DEPOSITS: The Soda Lake and Silver Lake playas border the Soda Mountains on the east. They are discussed in some detail by Thompson (1929, p. 554–572) in connection with ground-water investigations in the Mojave region. Soda Lake playa is a wet or discharging type with alkali concentrations around the border. Most of the Silver Lake playa is dry and alkali-free. Its surface is very hard, and it allows safe passage of an automobile except for a short period after rains.

The two small playas west of Quartzite Hills and Dolomite Mountain are evidently in the process of being buried by wind-blown sand and flooded by fine alluvial debris.

Structural Geology

General Statement

The rocks in the Soda Mountains record at least three periods of severe structural deformation. The earliest deformation may be Precambrian. The period involving low-angle thrusting and subsequent block faulting is probably Cretaceous and a part of the Nevadan-Laramide orogeny. A later period involved mainly lateral faulting and associated block faulting, which is essentially post-early Pliocene.

The areas east and west of the Soda-Avawatz fault zone differ greatly in their records of deformation. The area west of the Soda-Avawatz fault zone is here called the western area, and that to the east is called the eastern area.

Precambrian Deformation

In view of the dubious age of the gneissic complex, evidence in the Soda Mountains is not clear for the well-known and widespread post-Archean pre-Algonkian period of intense deformation, metamorphism, and intrusion. The strong gneissic trend of N. 60°–70° W. was established probably during the Precambrian era. This strong trend may have controlled the over-all deformational pattern in the Quartzite Hills. It also may have exerted a deep-seated control on the N. 60°–70° W. dike swarm in the western area.

Middle to Late Mesozoic Deformation

Eastern area.—Cenozoic deformation, uplift, and erosion have removed all but several isolated remnants of older metasedimentary rocks which record regional thrusting and block faulting, for the most part before Late Mesozoic (?) granitic invasion.

THRUSTING IN THE QUARTZITE HILLS AREA: The structural complex in the Quartzite Hills involves essentially east-west trending, gently south-dipping thrust faults with superposed north-south vertical faults. Lower Cambrian (?) metasedimentary rocks have been thrust over Upper Precambrian (?) metasedimentary rocks. The two major thrust faults, one cropping out low on the northeast flank of the Quartzite Hills (F, G-12) and the other cropping out in fault blocks in the southern part of the hills (H, I-11, 13), are probably parts of one large thrust complex.

The thrust mass moved along a limestone and dolomite zone and effected an indeterminable amount of tectonic reduction and accumulation of strata low in the overriding mass, as is shown by great variability in thickness and internal deformation. The thrust zone proper generally exhibits brecciation in the allochthon (Pl. 8, fig. 2). In a few places differential movement was absorbed by plastic flowage, which carried along small blocks from the autochthon (Pl. 8, fig. 1). The predominance of yield by fracture rather than flow suggests that thrusting occurred at a shallow level in the crust.

Evidence bearing on the relative direction of thrusting in the Quartzite Hills area is not conclusive, owing largely to the complex post-thrusting deformation and intrusion. The southerly dip of thrust zones, imbricate slicing and bedding, as well as a few folds in the limestone which are overturned to the north, implies that the allochthonous rocks moved relatively northward.

The tectonic framework of the Quartzite Hills area cannot as yet be correlated structurally with other parts of the Soda Mountains or adjacent ranges, but it must be remembered that the only rocks involved in this isolated thrust complex are Upper Precambrian (?) and Lower Cambrian (?), and they are not known definitely to occur in adjacent areas.

The thrusting preceded vertical faulting and invasion of granite, migmatite, and quartz diorite of the pre-Tertiary plutonic complex. On moderately strong evidence, the plutonic rocks are tentatively regarded as Upper Mesozoic. Hence the age of the thrusting may be Middle or Late Mesozoic (Nevadan-Laramide).

THE DOLOMITE KLIPPEN: Scattered masses of pre-Mesozoic carbonate occurring on Hopeless Hill, South Lakeshore Hill, and Dolomite Mountain (Pl. 4, fig. 1) are believed to represent the remnants of a regional thrust plate of minimum extent of 5 by 10 miles. It has been invaded by plutonic intrusions. Chaotic deformation involving steep dips prevails within the unit, although at places a rather steep east dip and north or northwest strike prevail. The attitude of bedding and innumerable shears shows that the carbonate unit was irregularly isoclinally folded and thrust-faulted on a grand scale. Deformation by both flowage and fracture seems to have been significant.

The thrust fault is locally preserved at the contact of the carbonate rocks with the gneissic complex (N-12, 13; P-17) and is marked by structural discordance. Upper Mesozoic (?) granitic rocks invaded and destroyed most of the autochthon and the thrust fault, as well as an unknown amount of the allochthon (Pl. 4, fig. 1). Remnants of the thrust fault are nearly everywhere tilted, probably because of deformation attending plutonic intrusion and Late Tertiary orogeny. However, in the Moonshine area the relatively flat base of the carbonate mass suggests that the subjacent Teutonia quartz monzonite was stopped locally in its upward advance by the sole thrust. A similar situation is reported in the western Mojave region (Wiese, 1950, p. 39).

The usual evidence for determining the relative direction of thrusting, such as drag, imbrication, and diagnostic field relations, is lacking in the Soda Mountains. The prevailing strike of the beds and folds is northwesterly, and therefore the movement of the allochthon was probably either to the northeast or to the southwest. Hewett (1956, p. 50–61) demonstrated that all major Laramide thrust sheets were driven from west to east in the Ivanpah quadrangle to the east of the Soda Mountains. Local details show that possibly correlative carbonate rocks in the Silurian Hills moved south-southwestward in a thrust plate, probably during the Tertiary (Kupfer, 1954). In the Soda Mountains the major thrusting of the carbonate body antedated the Upper Mesozoic(?) granitic rocks, although movement continued to a minor extent during and after intrusion, as evidenced by brecciated tactite in the Moonshine area. The isoclinal folding and thrusting of the dolomite mass are probably associated with the Nevadan-Laramide orogeny.

POST-THRUST BLOCK FAULTING: In the eastern area numerous north- to northwest-trending vertical faults transect the highly thrusted rocks of Early Cambrian (?) age in the Quartzite Hills and of Permian age on Baker Hill, but they are absent from wide areas of Upper Mesozoic(?) plutonic rocks (Pls. 1, 10). The amount of displacement, impossible to determine with precision, is estimated to be less than 500 feet vertically. Although these faults are roughly parallel with the Soda-Avawatz fault zone, evidence for significant lateral shift is lacking.

The age of this episode of block faulting is uncertain except that it is later than the thrusting. Since the faults do not cut the Upper Mesozoic (?) plutonic rocks they could have formed before intrusion, or they could have formed coeval with intrusion or after it but without penetrating the underlying intrusive rocks. In the western area, a generally similar type of block faulting, differing only in trend, falls largely between Late Mesozoic thrusting and granitic intrusion. On the basis of this comparison, the block faulting in the eastern area is tentatively regarded as essentially a post-thrusting and pre-intrusion phase of the Nevadan-Laramide orogeny.

STRUCTURE RELATED TO PLUTONIC INTRUSION: The exposed borders of the various plutonic rocks are vertical and subvertical everywhere except on the southeast side of Lakeshore Hill where they dip 45°–60° SE. The regional trend of the various bodies swings from northwesterly on Hopeless Hill and South Lakeshore Hill to northeasterly on Lakeshore Hill. Presumably this arc reflects a deep-seated pattern which may have some relation to the less pronounced curve in the Soda-Avawatz fault zone to the southwest.

Western area.—The Upper Paleozoic, Triassic, and Jurassic rocks in the western area record an episode of extremely complex thrust faulting and block faulting preceding Late Mesozoic plutonic invasion.

THRUSTING OF PALEOZOIC LIMESTONE: The blocks of Upper Paleozoic limestone which occur in the western area (Pl. 6, fig. 2; Pl. 7, fig. 1), on Highway Spur, and on Zzyzx and Baker hills represent downfaulted remnants of a large and internally faulted thrust complex. At no place in the Soda Mountains proper is the sole thrust of the limestone complex exposed. On Zzyzx Hill, however, isolated blocks of highly deformed Upper Paleozoic limestone similar to those in the Soda Mountains, rest at different levels with tectonic contact above the volcanic flow breccia of the Mesozoic Soda Mountain formation. Largely on the basis of these critical exposures, then, the writer believes that the thick succession of Upper Paleozoic limestones was regionally thrust over the Mesozoic volcanic and sedimentary rocks of the Soda Mountain formation.

The limestone masses composing Baker Hill and the highest part of Spectre Spur show numerous features of internal deformation which are less obvious or obliterated by contact metamorphism in the smaller masses in the area. Internal deformation of the Upper Paleozoic limestone units as a whole falls into the following three categories:

(1) Small-scale brecciation, shearing, and faulting into disordered wedges (Pl. 3; Pl. 7, fig. 2; Pl. 8, fig. 3). These are attributed largely to thrust faulting.

(2) Low-angle thrust faults. The outstanding example is the plate of Bird Spring limestone thrust over older (?) limestone on Spectre Spur (Pl. 6, fig. 2; Pl. 7). Below this plate is another thrust zone within the Mississippian-Pennsylvanian unit (Pl. 3; Pl. 6, fig. 2).

(3) Vertical to high-angle normal and reverse faulting without systematic trend. Most displacements are estimated to be less than several hundred feet. This faulting probably accompanied thrust faulting and merged into a stronger post-

thrusting phase. The high-angle faults are best exposed on Spectre Spur and the north end of Highway Spur (P, Q-10, 11).

The absence of stratigraphic markers and the paucity of diagnostic fossils prevent the determination of direction and amount of displacement. Local imbricate slicing and drag are helpful but also confusing. In spite of intense deformation, most of the isolated blocks of limestone in the Soda Mountains show bedding that strikes in a northerly to northwesterly direction and dips vertically or steeply eastward. Complete folds are surprisingly rare. A few prominent drag structures and imbricate slices in east-dipping thrust zones, together with east-dipping beds, suggest that some of the internal thrust blocks as well as the entire thrust complex may have moved westward relative to the underlying rock masses. However, a westward-directed tectonic drive during the Nevadan-Laramide orogeny in this region appears anomalous in view of the eastward movement of major thrust masses occurring near by to the east in the Ivanpah quadrangle. The magnitude of displacement is unknown, but the writer feels that displacement produced by internal thrusts probably does not amount to more than several thousand feet and that displacement of the allochthonous limestone as a single thrust complex is probably at least several miles. Certain determination of direction and magnitude of thrusting during the Nevadan-Laramide orogeny in the Soda Mountains region remains an inviting problem.

DEFORMATION OF THE SODA MOUNTAIN FORMATION: The Soda Mountain formation appears to be para-autochthonous with respect to the thrust Upper Paleozoic limestones described above. Where stratification occurs, the tectonic structure is exceedingly complex and practically impossible to decipher satisfactorily, since marker beds are absent and stratification is discontinuous. The succession on Spectre Spur, the relatively least deformed in the area, dips steeply eastward and is cut by innumerable faults, which are chiefly vertical and northeast-trending. The volcanic and sedimentary rocks of Highway Spur dip steeply to the west and east; they are intricately cut by numerous faults and shears. The structure here is most complex because of the impact of at least four types of deformation since Late Mesozoic time: thrusting, block faulting, lateral faulting, and crude anticlinal folding. Also, in the Soda Mountain formation, part of the structural complexity may be attributable to faulting and folding contemporaneous with deposition.

POST-THRUST BLOCK FAULTING: In the Soda Mountains, the Paleozoic limestones and Mesozoic volcanic rocks are everywhere juxtaposed along essentially vertical faults, which have relatively dropped rectilinear masses of the allochthonous limestone into the para-autochthonous volcanic rocks. Internal structures in the limestone—low-angle thrusts and small-scale block faults (Pl. 3; Pl. 7, fig. 2) that formed during thrusting—are strongly displaced by these later faults.

The largest block of limestone occurs on Spectre Spur (Pl. 6, fig. 2; Pl. 7, fig. 1); smaller masses of various shapes occur at both ends of Granite Ridge, in the Blue Bell Mine area, and on Highway Spur. The amount of displacement generally associated with the fault blocks is unknown, but it is estimated to be at least 2000 feet. The two long northeast-trending faults which bound the limestone mass on Spectre Spur reveal a minimum vertical displacement of about 2500 feet. There is no evidence for or against lateral component of movement. These faults trend strongly northeast on Spectre Spur and west to northwest in other areas west of the East fault in the Soda-Avawatz fault zone.

STRUCTURE RELATED TO LATE MESOZOIC PLUTONIC INVASION: The northern intrusive boundary of the main plutonic mass (0-6) trends largely in harmony with the vertical faults in the area. This strongly suggests that the upward advance of granitic material was at least partially controlled by pre-existing structure. Plutonic invasion for the most part post-dated block faulting as evidenced by unsheared granitic rocks which truncate the faults.

The intrusion of granite in long vertical dikes parallel and close to the Soda-Avawatz fault zone proves a definite relation between plutonic invasion and regional strike-slip faulting. More regional data must be accumulated, however, before determining whether plutonic activity or tectonic stress predominated in establishing the basic trend in Late Mesozoic time.

Regional Integration of Late Mesozoic Deformation

Within the Soda Mountains, some salient features of deformation assigned to the Late Mesozoic or Nevadan-Laramide orogeny are outlined as follows:

(1) Three thrust complexes, each defined by characteristic lithology and deformation, appear to be involved. They are not in contact with one another nor can they be directly related mechanically.

(2) The strike of most of the beds involved in thrusting is predominantly north and northwest; in the Quartzite Hills, however, the strike is northwest, east-west, and northeast.
(3) Lithologic correlatives of the thrust-faulted sedimentary rocks are preserved to the northeast. Igneous activity and metamorphism have obliterated much of the Paleozoic and Mesozoic record to the southwest.
(4) The two large thrust complexes (those involving the dolomite klippen and the Upper Paleozoic limestones) moved either westward or eastward. Internal evidence weakly suggests that the Upper Paleozoic limestone mass may have moved westward, but regional tectonic analysis favors eastward movement. The small complex in the Quartzite Hills probably moved northward.
(5) Block faulting occurred partially in conjunction with overthrusting but mainly after it; most occurred before plutonic invasion.
(6) Overlap of thrusting, vertical faulting, and intrusion is evident, although the major part of the orogeny occurred before passive plutonic intrusion and established some structural control over it.

Mesozoic deformation in the Soda Mountains appears to be in general accord with the orogenic history of the southern part of the Great Basin and more specifically the Mojave Desert as integrated and summarized by Nolan (1943, p. 173–178) and Hewett (1954, p. 12–15). In comparison to the well-preserved orogenic record in the Ivanpah quadrangle to the northeast, the central and western part of the Mojave Desert reveals only fragmentary and obscure evidence of the nature and extent of Mesozoic deformation.

West of the Soda Mountains in the central Mojave Desert, McCulloh (1952, Ph.D. thesis, Univ. Calif.) reports the probable presence of large-scale and complex thrust masses which are metamorphosed and invaded by Jura-Cretaceous plutonic rocks. To the east and northeast of the Soda Mountains, Hewett (1956, p. 50–61) mapped five large low-angle west-dipping thrust faults which are separated by open folds and are intruded by Teutonia quartz monzonite. Successively western and higher thrusts brought progressively older (lower) formations upward and eastward. Normal faulting was followed by major thrusting, and that in turn was followed by invasion of quartz monzonite. This sequence of thrusting, block faulting, and intrusion is also observed in the Soda Mountains. The complexity of thrusting increases in a westerly direction in the Mojave Desert. This is in accord with the change from miogeosynclinal to eugeosynclinal environment in a westward direction.

Cenozoic Soda-Avawatz Fault Zone

GENERAL STATEMENT: The profound zone of lateral faulting that dominates the tectonic pattern in the Soda Mountains is herein called the Soda-Avawatz fault zone (Pls. 1, 2, 10). It is exposed for 9 miles in the Soda Mountains and is believed to continue southeastward many miles under the Soda Lake playa and northward under alluvium to the southern end of the Avawatz Mountains. It undoubtedly continues many miles northward along one or more strike-slip fault zones in the Avawatz Mountains. The Death Valley fault zone, rather than the Garlock fault, appears to represent the northern continuation of the Soda-Avawatz fault zone (Fig. 3).

DESCRIPTION AND DISCUSSION: Along most of its course, the Soda-Avawatz fault zone is bound by the large through-going West and East faults, between which occur another through-going fault and numerous secondary readjustment faults. The width of the fault zone ranges from 1 to 2 miles. All formations, except modern alluvium, in the Soda Mountains are involved in the faulting, and locally (P-12) even alluvium is slightly tilted. The rocks east of the fault zone differ markedly from those within and west of it (Pls. 1, 10).

The salient features of deformation are outlined below:

(1) Most of the displacement (oblique slip) has taken place on three through-going vertical to subvertical faults—the West fault, the East fault, and a third fault about 2000 feet west of the East fault (Figs. 4, 5).
(2) The major faults are characterized by a vertical zone, 10–500 feet wide, of intense granulation, brecciation, mixing of different rock types, and numerous highly sheared slivers and wedges of different rocks (Pl. 9, fig. 3). In places they are several hundred feet in length and are bound by almost horizontal slickensides and corrugations.
(3) Numerous small subvertical faults cut all formations within the zone. These secondary faults are generally aligned en

echelon (northwest-trending) in a belt parallel with the major shears (Fig. 4). Some are thrust faults which indicate a north-south or northeast-southwest direction of compression. Minor vertical and normal faults trend at right angles to the echelon faults.

(4) A major anticlinal uplift with axis trending northwesterly, or slightly oblique to the major faults, occurs within the fault zone on Highway Spur (Figs. 4, 5). The older rocks, which are exposed in the higher parts of the structure, are so intensely sheared and disorganized that they suggest the fold was essentially squeezed upward by strong compression associated with strike-slip faulting. A syncline cut by several longitudinal high-angle faults occurs south of the anticline and in echelon relation to it.

(5) In the Granite Ridge area (N, O, P–9, 10) rocks on the west side of the West fault are apparently elevated, while on Highway Spur (Q, R, S, T,—10, 11

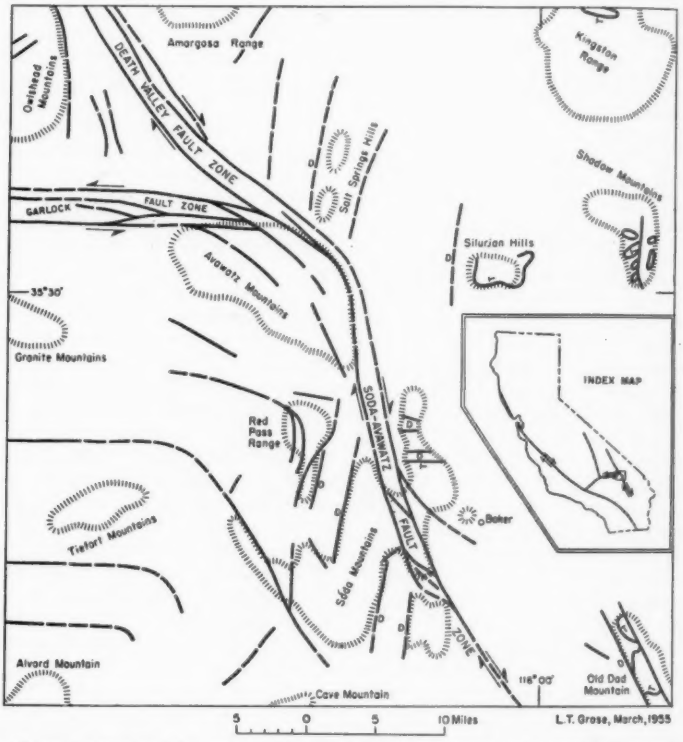

FIGURE 3.—CENOZOIC FAULT MAP OF THE SOUTHERN DEATH VALLEY AND SODA MOUNTAINS REGION
Contributors of structural data: A. M. Basset, F. M. Byers, L. T. Grose, D. F. Hewett, R. H. Jahns, C. J. Kundert, D. H. Kupfer, J. F. McAllister, L. F. Noble, B. W. Troxel, and L. A. Wright

rocks on the west side of the faults are apparently depressed. These relationships might indicate hinge faulting. There is no evidence, however, of diminishing deformation toward a "point of zero displacement." The apparent reversal of throw is probably largely due to right-lateral displacement along the West fault which placed unlike rocks in juxtaposition.

Each of the above characteristics of the Soda-Avawatz fault zone constitutes evidence for large lateral component of displacement; items 3, 4, and 5 support right-lateral movement. Some features similar to these along the San Andreas and Garlock fault systems of southern

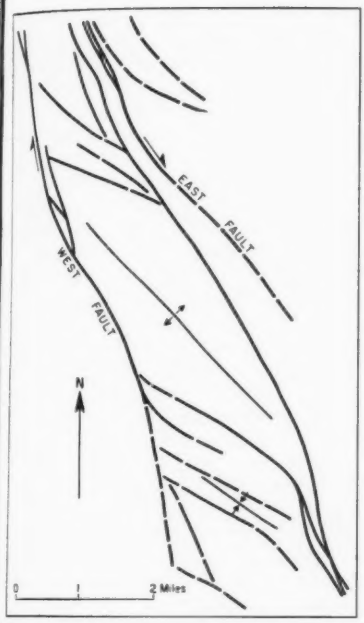

FIGURE 4.—ECHELON PATTERN OF MAJOR FAULTS AND FOLD AXES SUGGESTING RIGHT-LATERAL DISPLACEMENT ON THE SODA-AVAWATZ FAULT ZONE IN THE SODA MOUNTAINS

California have been described by several workers (Noble, 1953; 1954; Wallace, 1949; Wiese, 1950, p. 39–44; Hill and Dibblee, 1953, p. 445–446; Muehlberger, 1954; Allen, 1957, p. 336–343). The strongest evidence for predominant right-lateral movement along the Soda-Avawatz fault is the over-all geometry of the fault zone, that is, the echelon pattern of subsidiary branching faults and fold axes (Fig. 4). Detailed maps of the San Andreas fault zone strikingly portray a similar fault arrangement (Wallace, 1949; Noble, 1953; 1954). The amount of right-lateral displacement is impossible to determine with precision. Although similar formations crop out on both sides of the West fault, they are disposed in such a mosaic of fault blocks and roof pendants that specific geologic features of small scale cannot confidently be matched across the fault. The profound difference in rock types and ages between the areas west and east of the Soda-Avawatz fault zone may well be taken as evidence for large lateral displacement. The fault zone may essentially reflect the original boundary between the two areas of different geologic formations. Until further work is carried out in the region, the amount of lateral displacement will remain unknown, but in the writer's opinion it is probably on the order of 3 miles and possibly much greater.

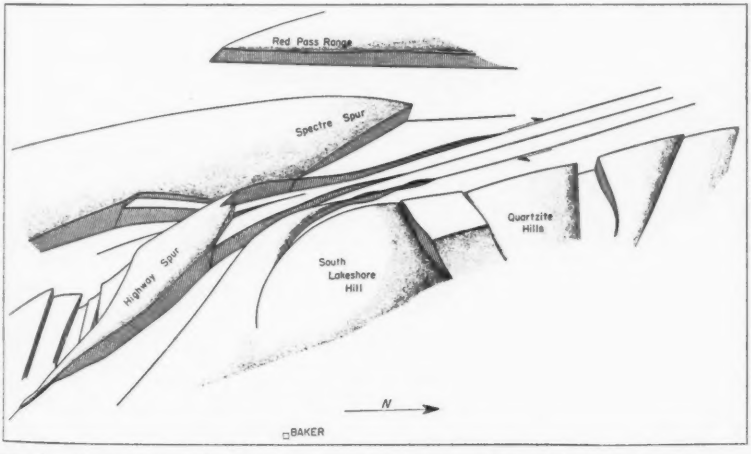

FIGURE 5.—DIAGRAMMATIC DRAWING OF THE SODA-AVAWATZ FAULT ZONE AND BLOCK FAULTS OF LATE TERTIARY AGE IN THE SODA MOUNTAINS

View is oblique and westerly. Pliocene Avawatz formation is "peeled off" exposing estimated general configuration of pre-Cenozoic "basement" rocks. Scale is about 18 miles from left to right and 12 miles from foreground to background.

AGE: The youngest formation exposed in the Soda Mountains that is cut by the Soda-Avawatz fault is the lower Pliocene Avawatz formation. It has been displaced at least several thousand feet and possibly several miles. This indicates that large displacement has occurred since early Pliocene time. There is no evidence for recent faulting, such as offset drainage, scarplets in alluvium, or seismic activity, which typify the San Andreas and Garlock faults. Recent warping is manifest locally along the East fault (P-13) by dips up to 12° in modern alluvium. The possibility of an ancestral Soda-Avawatz fault zone existing as early as Cretaceous time is suggested by Cretaceous(?) granite dike intrusions close to and parallel to the fault zone.

Other Faults of Late Cenozoic Age

Faults of Cenozoic age other than those in the Soda-Avawatz fault zone occur scattered through the Soda Mountains (Figs. 3, 5; Pls. 1, 10). The largest is the Far West fault, which crops out west of the Blue Bell Mine area and probably continues northward under alluvium along the base of the western side of Spectre Spur. Vertical displacement of at least 2500 feet and possibly some horizontal displacement are involved. Older faults in a crush zone, locally up to 2000 feet in width and occurring in the complex just east of the Far West fault, have been reactivated in the Cenozoic era presumably in adjustment to stresses along the Far West fault.

Vertical and probably normal faults occur around the Blue Bell Mine area and the northwest end of Ruin Flat. These are related to tectonic subsidence of the Avawatz formation underlying Ruin Flat. North of Quartzite Hills two east-west vertical (?) faults bound a remnant of Upper Tertiary (?) fanglomerate (F-11), and south of Lakeshore Hill a prominent east-west vertical fault separates fanglomerate from basement plutonic rocks (K, L-12). Half a mile southward low-angle south-dipping thrust faults, which are overlapped by Upper Tertiary (?) fanglomerate, have sheared a wide zone in Upper Mesozoic (?) plutonic rocks. They represent the only known low-angle thrust faults of probable Tertiary age in the area.

Regional Integration of Late Cenozoic Deformation

The broad types of Cenozoic structure that have been reported as significant in the region are chaos structure (Chaotic shingling of thrust slivers), low-angle thrust faults, high-angle normal and reverse faults, folds, and strike-slip faults. The generalized fault map (Fig. 3) illustrates an integrated tectonic pattern of Late Cenozoic deformation in the Soda Mountains region.

Some features in the Soda Mountains might be interpreted to represent chaos structure similar to that described by Noble (1941, p. 963–977) in the southern Death Valley area and by Kupfer (1951) in the Silurian Hills. These features are the intense faulting in the Soda Mountain formation in Highway Spur (S, T, U–12-14) and the anomalous occurrence of huge masses of limestone in the Avawatz formation. They are here interpreted, however, as being caused by complex shearing attending strike-slip faulting and by landsliding respectively. Deformation of the chaos type is not present in the Soda Mountains.

Klippen representing low-angle thrust faulting of Late Tertiary age have been reported by Hewett (1956, p. 86–101) in the Kingston Range, Shadow Mountains, and Old Dad Mountains, all east of the Death Valley–Soda-Avawatz fault zone. Hewett suggests that the klippen indicate a great thrust plate that moved eastward. The geology of the Soda Mountains appears to be unrelated to this Late Tertiary regional thrusting. The only thrust faulting of probable Late Cenozoic age in the Soda Mountains occurs north of South Lakeshore Hill, and it is a local deformation of little regional significance.

Deformation associated with regional strike-slip faulting, rather than complex thrusting, prevailed during the Late Cenozoic in the Soda Mountains region. The Soda-Avawatz fault zone is believed to continue northward along the base of the Avawatz Mountains (Grose, in Wright and Troxel, 1954, p. 43) and join the Death Valley fault zone. The latter displays right-lateral movement and features similar to the San Andreas fault (Noble and Wright, 1954, p. 157). The Death Valley—Soda-Avawatz fault may extend some distance southeast of Soda Lake under the younger Cenozoic volcanic rocks (type section in the Bristol Mountains), but the evidence indicates that the fault is older and less pronounced in the southeastern Mojave region than to the north (Bassett, A. M., and Kupfer, D. H., 1955, personal communications).

One of the most important tectonic problems in the region concerns the eastern portion of the

Garlock fault and its relation to Late Cenozoic thrusting and lateral faulting. The problem is by no means solved, for the critical area, the Avawatz Mountain block, is unmapped. However, the structure in the Soda Mountains has a direct bearing on the problem. Hewett (1955, p. 382, 386; *in* Nolan, 1943, p. 185–186) suggested that the Garlock fault turns on the northeast flank of the Avawatz Mountains from an east-west trend to an essentially north-south trend. Hewett postulated that the fault, accompanying this turn, changed from a vertical left-lateral fault to a moderately west-dipping thrust. He believes that the thrust passed east of or through the Soda Mountains and suggests that movement of the Garlock fault may bear a direct relation to the Upper Tertiary thrust and chaos structure in the region to the east.

Structural studies in the Soda Mountains have yielded no evidence of large-scale eastward thrusting during the Cenozoic era that can be related to movement on the Garlock fault. Instead, the prominent structural feature is the Soda-Avawatz fault which joins the Death Valley fault, and together they constitute a single, highly inclined to vertical, right-lateral fault zone to the east of which the Garlock fault does not occur. The Garlock fault is currently active, as manifest by offset drainage (Muehlberger, 1954), whereas the Soda-Avawatz fault does not exhibit features of recent movement. More recent movement on the east-west Garlock fault has forced an eastward bulge in the Death Valley—Soda-Avawatz fault where the faults join on the northeast side of the Avawatz Mountains (Fig. 3). The Garlock fault is to a lesser extent bent southeastward at the junction. Also at the junction of the faults, the Avawatz Mountain block abruptly rises 5000 feet above the surrounding terrain. It appears that neither fault actually truncates or offsets the other; rather, the interference is accommodated by large-scale crustal drag of both faults and great local uplift. Although the Death Valley—Soda-Avawatz fault appears to dominate the regional tectonic pattern, since it is through-going, the greater drag effect and local uplift are caused by movement along the Garlock fault. This testifies to more recent and powerful influence of movements along the Garlock fault.

As pointed out previously, the Soda Mountains area is situated in a north-south or northwest-southeast zone of transition between miogeosynclinal and eugeosynclinal environments, which more or less persisted throughout the Late Paleozoic and Mesozoic eras. The Death Valley—Soda-Avawatz fault zone appears to lie within this transition zone. The crustal discontinuity between the two regions constituted a general zone of weakness which may have determined the position of the Death Valley—Soda-Avawatz fault zone.

Summary of Geologic History

During Late Precambrian and Early Cambrian time the Soda Mountains area was a shallow sea bordering a land mass to the east. Several thousand feet of impure cross-bedded quartzite with subordinate layers of limestone and dolomite was deposited.

By Middle Paleozoic (?) a deep neritic environment may have prevailed, as suggested by the presence of a thick, almost uniform succession of dolomite and limestone which lacks near-shore features. Sedimentation continued in Late Paleozoic time. The region became somewhat unstable as orogenic activity increased to the west, but there is no direct evidence in the Soda Mountains area of the Late Paleozoic orogeny that is reported to have affected the rocks exposed in the central and western Mojave Desert. Upper Paleozoic marine limestone, marl, quartzite, and chert accumulated to an estimated thickness of at least 11,500 feet.

Marine sedimentation probably continued from Late Paleozoic into Early Triassic. At least 1700 feet of Lower Triassic strata reveals an upward gradation from limestone into siltstone and fine sandstone of shallow-water environment. These grade into continental sandstone intercalated with andesite breccia. Thus, the marine environment which had persisted throughout the Paleozoic era came to an end in Early or Middle Triassic time.

Continental volcanism and sedimentation followed and lasted from Middle Triassic (?) to at least Middle Jurassic (?). Andesite flow breccia, pyroclastic rocks, and nonmarine quartzite represent this episode in the history of the area.

Strong deformation associated with the Nevadan-Laramide orogeny followed during Late Jurassic and Cretaceous time. It involved regional thrust faulting and block faulting. Granitic invasion succeeded the major phase of orogeny, but deformation recurred feebly. Innumerable dikes of diabase and felsite were formed shortly after the granitic magma crystallized.

A long period of uplift and erosion lasted

from Eocene to late Miocene. During the early Pliocene several thousand feet of coarse continental clastic sediments and lake beds accumulated in local basins associated with vertical and strike-slip faulting.

From mid-Pliocene through Pleistocene the area was regionally uplifted, folded, faulted, and eroded. Strike-slip movement took place along the Soda-Avawatz fault zone. Evidence for Recent faulting is lacking. The latest deformation involved gentle uplift along a northeast-southwest axis through South Lakeshore Hill and Granite Ridge. It raised semiconsolidated lower Pliocene fanglomerate to some of the highest elevations in the Soda Mountains (Pl. 2).

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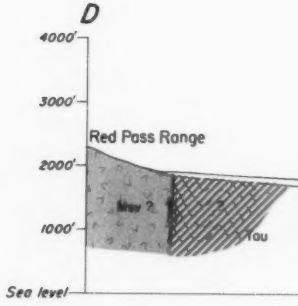
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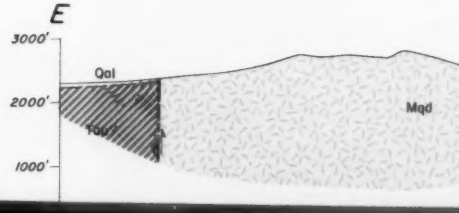
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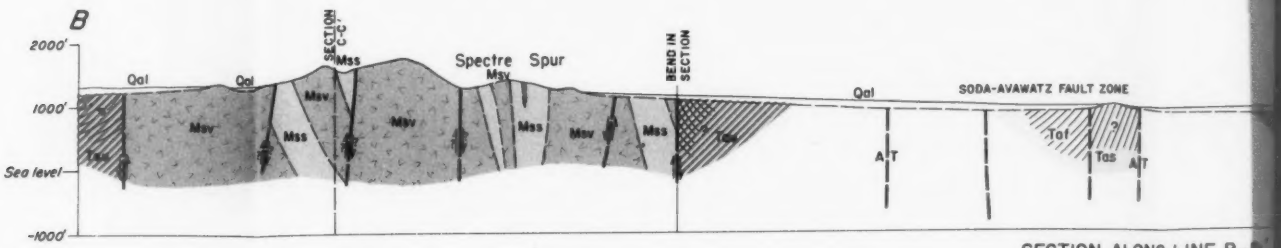

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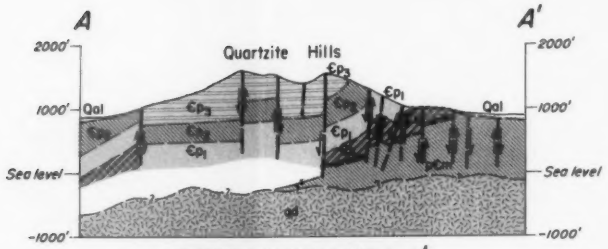

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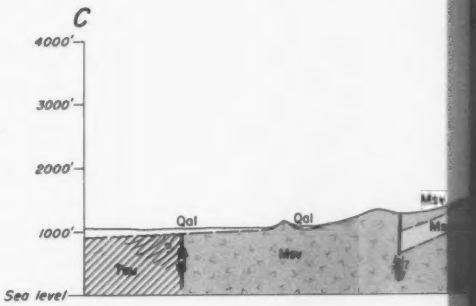

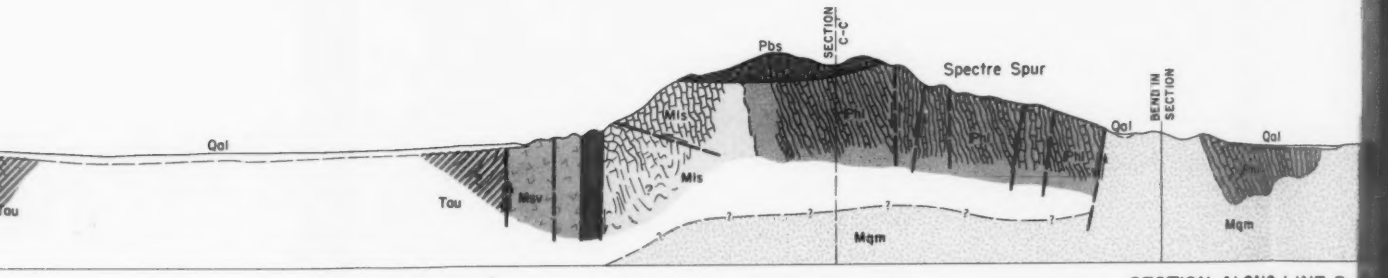

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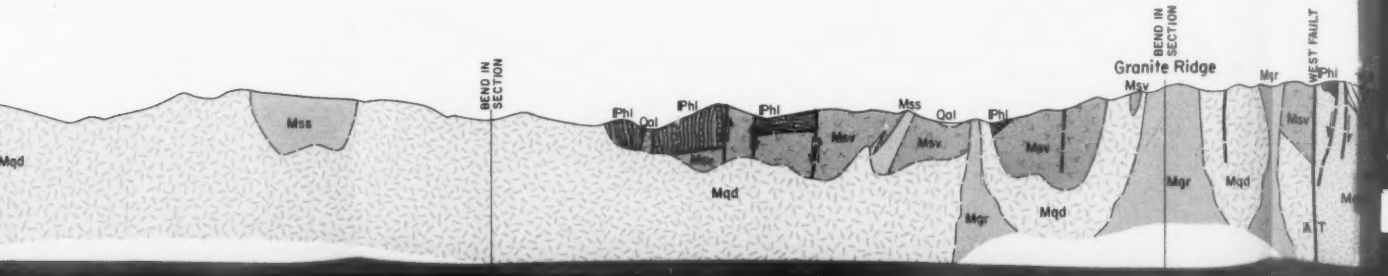

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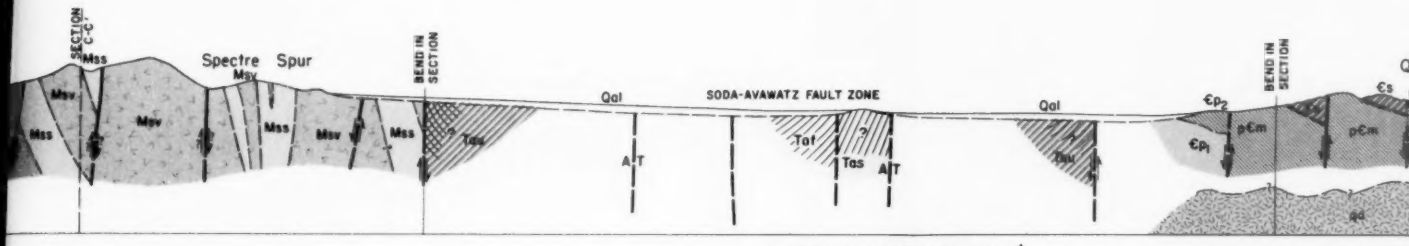

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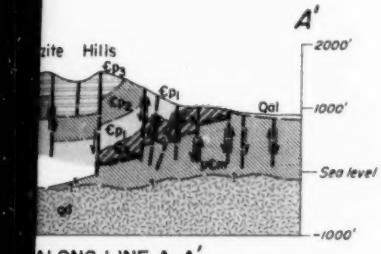

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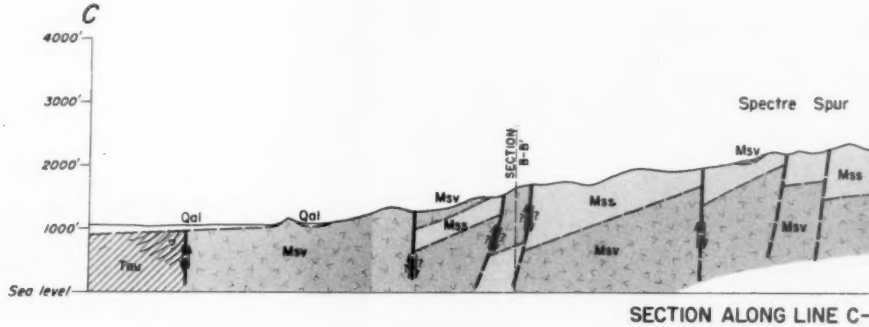

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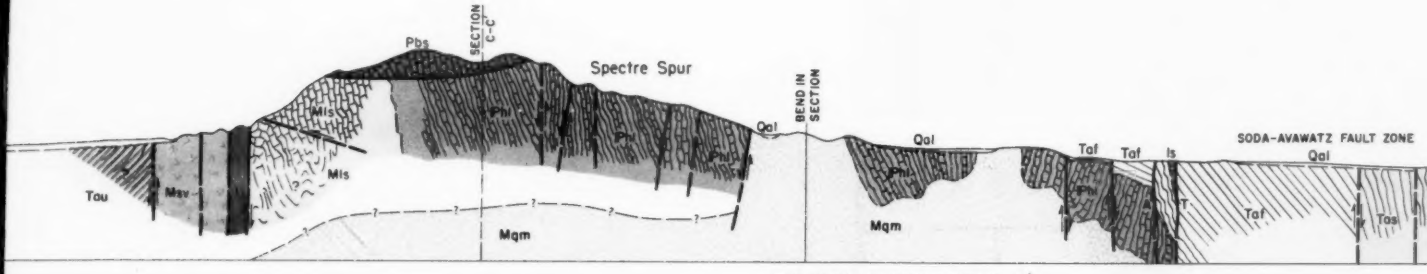

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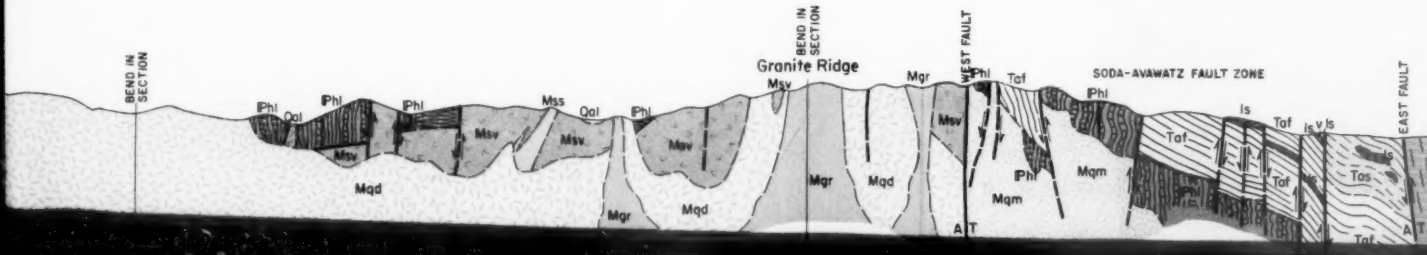

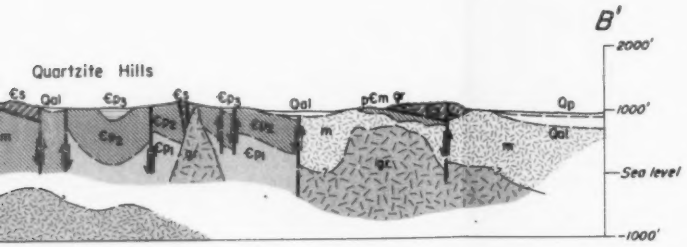

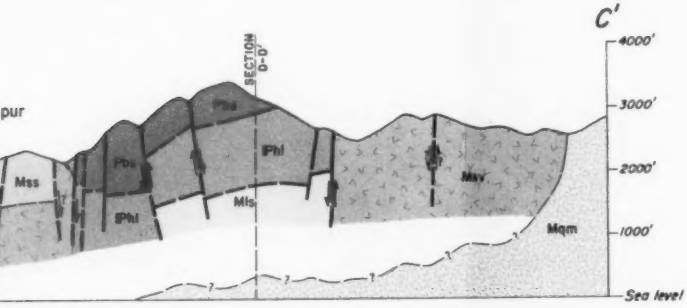

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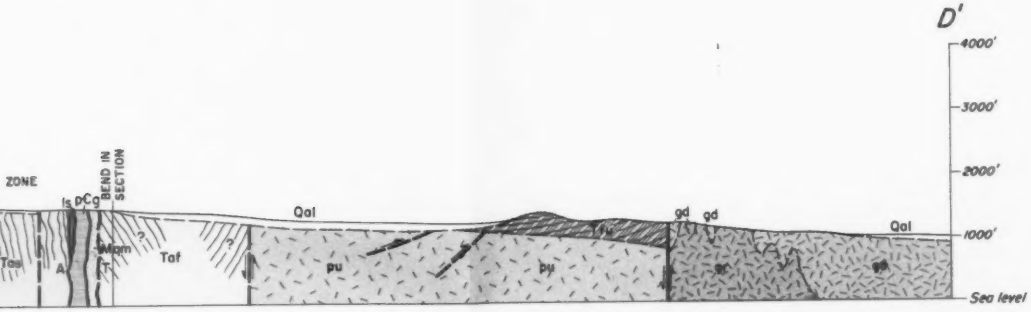

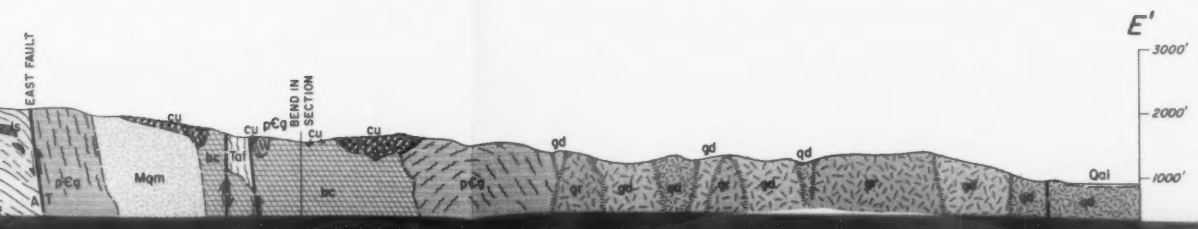

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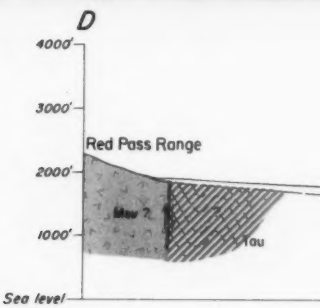

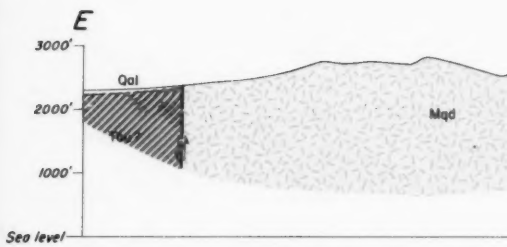

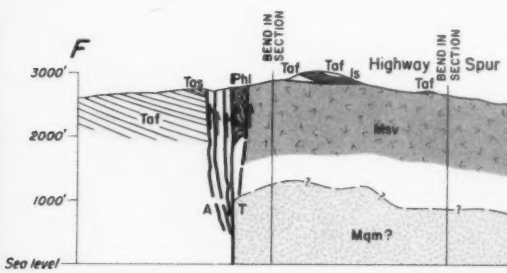

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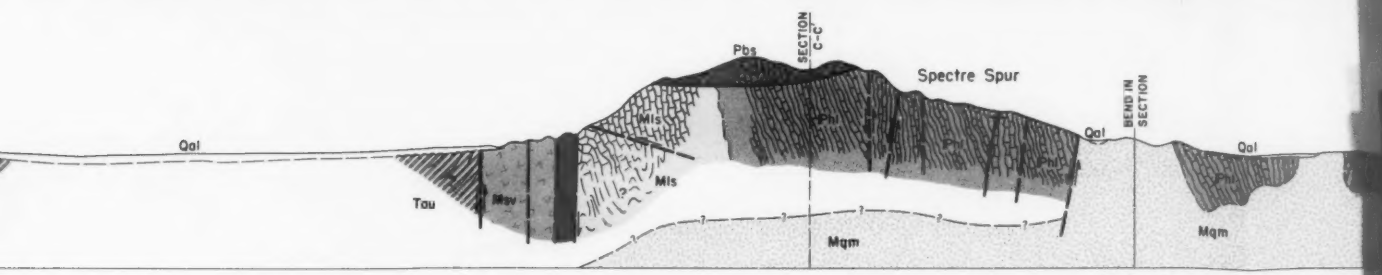

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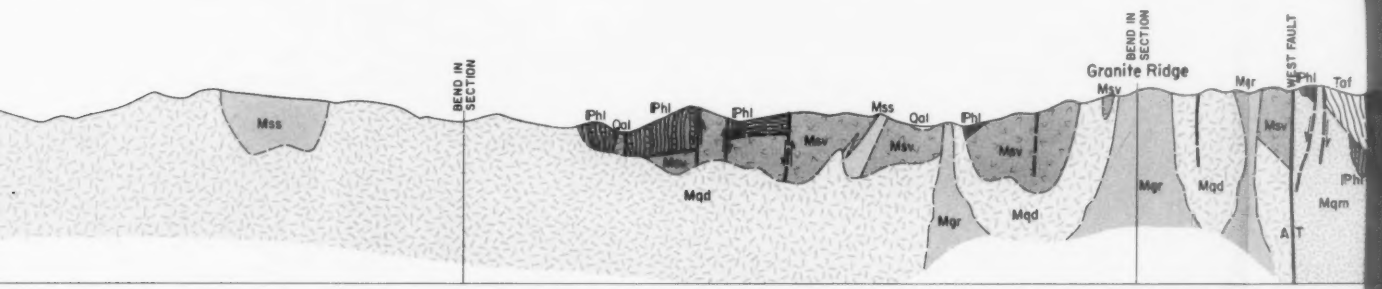

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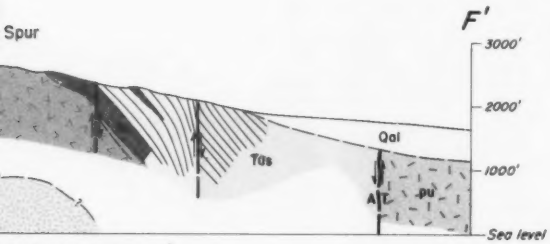

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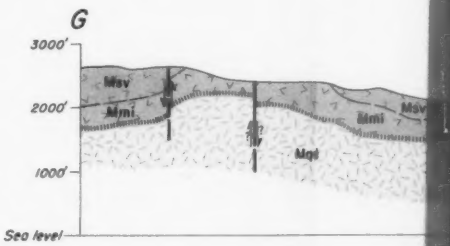

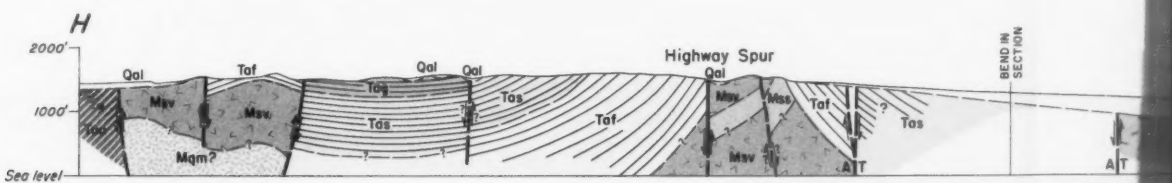

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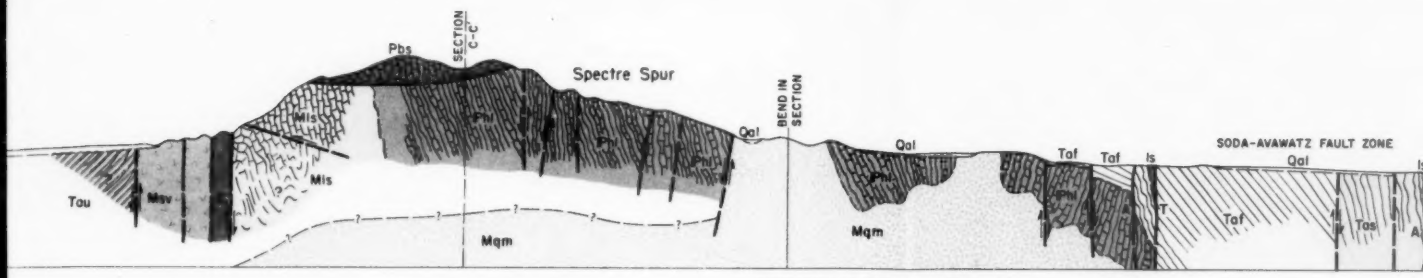

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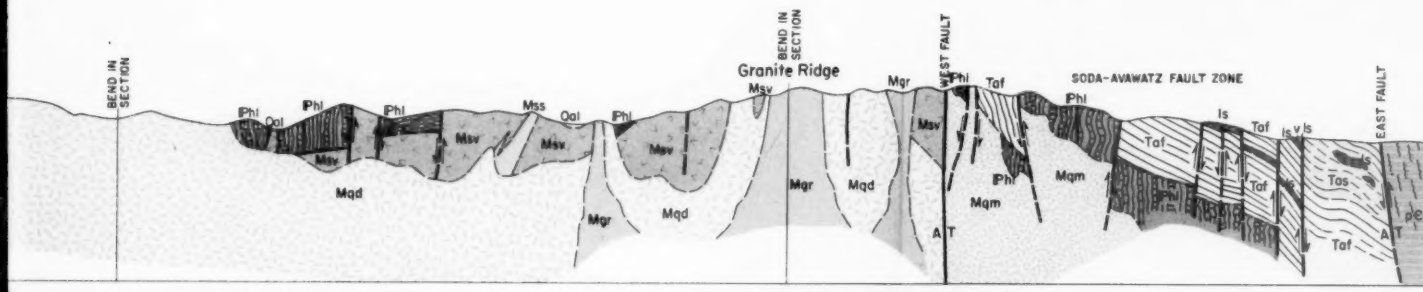

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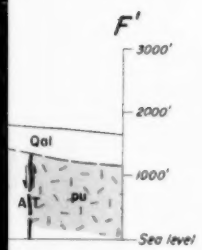

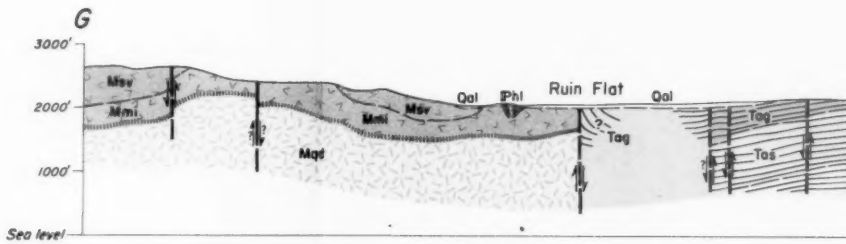

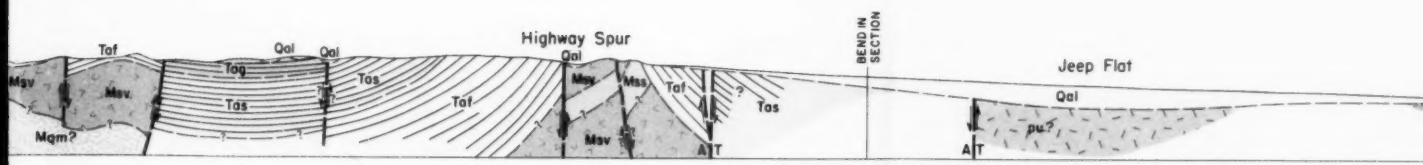

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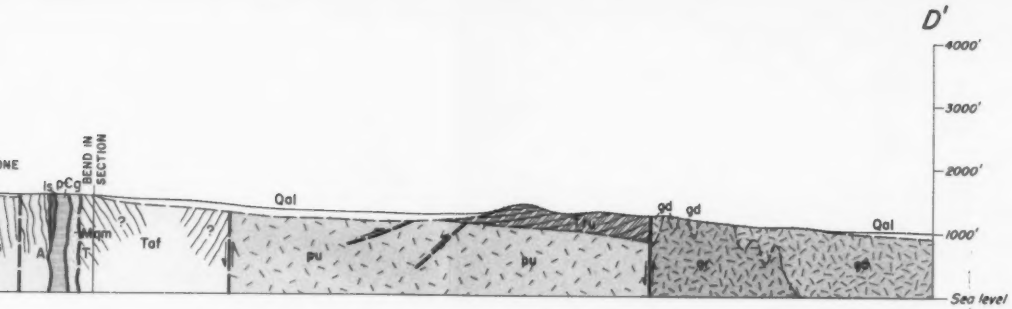

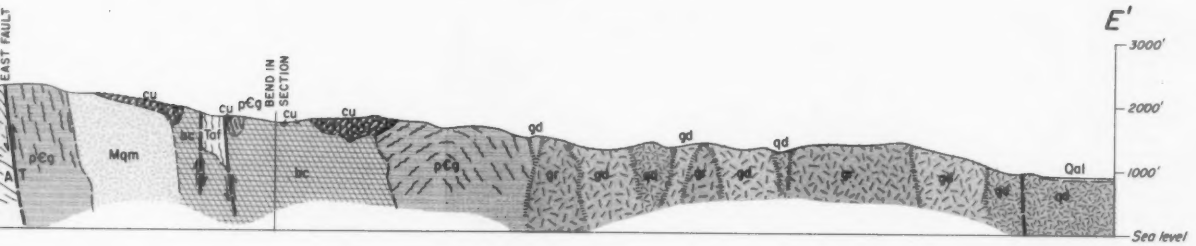

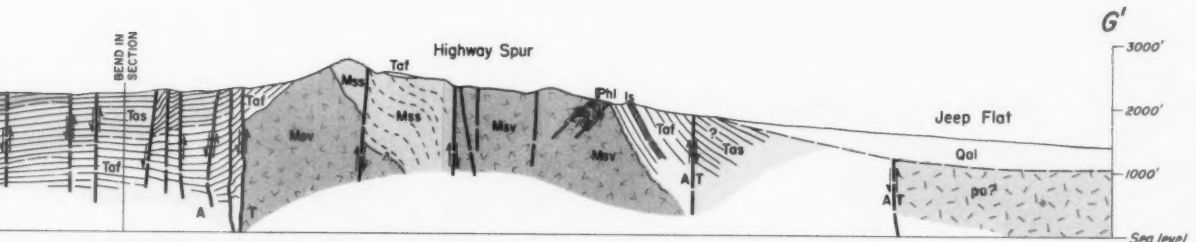

SECTION ALONG LINE G-G'

SAN BERNARDINO COUNTY, CALIFORNIA

Short Notes

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 70, PP. 1549–1552, 1 FIG. DECEMBER 1959

ANOMALOUS SEDIMENT DEPOSITION ON THE FLANK OF ENIWETOK ATOLL

BY M. N. BRAMLETTE, J. L. FAUGHN, AND R. J. HURLEY

Some short cores from the shelf at about 800–1000 fathoms on the southwest flank of Eniwetok Atoll (Fig. 1) penetrated Pliocene deposits with little to no later sediment cover. Of the 11 cores, 5 did not penetrate the upper Tertiary, although these were only 4 to 46 cm in length, and the Quaternary cover may thus be only slightly thicker than in the others. Where present, the thin veneer of recent or Quaternary sediment is strikingly different from the sediment of the upper Tertiary.

The Quaternary deposits include much coarse reef debris, particularly the fragments of algae such as *Halimeda* and other shallow-water material up to several millimeters in grain size, mixed with varying amounts of pelagic Foraminifera. The Pliocene sediments (one may be upper Miocene) are pure pelagic deposits of much finer grain size, consisting of coccoliths and pelagic Foraminifera with no admixture of reef material.

Bottom photographs show areas of well-developed ripple marks in coarse sediment (C. J. Shipek, manuscript) apparently formed only in the areas with the veneer of post-Tertiary coarse sediments. Evidently this shelf is now an area of agitated water which has permitted only a little and localized accumulation of the coarser sediments during Quarternary time. The marked contrast with the upper Tertiary fine-grained pelagic sediments (without reef material) is significant. The Tertiary sediments must have accumulated under topographic conditions rather similar to those of the present, as drilling has shown typical reef material from the surface of the atoll down into similar Tertiary reef deposits. The top of the Tertiary was not determined in the boring but was evidently much above the 1-mile depth of this shelf, as Miocene fossils were encountered at 620 feet (Ladd *et al.*, 1953, p. 2272). The near-surface reef material supplied through surface-wave action, perhaps most actively during glacial changes in sea level, is easily carried down the steep flanks of the atoll. Such debris, although presumably supplied at the base of the steep slope during the Tertiary also, evidently was not carried out over most of the shelf during that time, even though these Tertiary shelf deposits must have been almost as near the steep slope of the atoll. The continued growth of the reef during the Tertiary does not allow for any period of different conditions such as a subsidence to much greater depths below the water surface.

Much less water agitation on the shelf during the late Tertiary is also indicated by the great abundance of the tiny coccoliths in the Tertiary deposits. The coccoliths range from about 2 to about 10 microns, yet they form about half these unsorted pelagic deposits. Fine-grained constituents have been winnowed out and form a negligible part of the recent deposits.

The upper Tertiary sediments have been somewhat indurated by secondary calcite cementation, evidently related to the considerable corrosion and secondary growth evident on the coccoliths. A brown impregnation at the top and extending down as mottling for a few centimeters is also usual in the Tertiary sediment of the cores. This seems to consist of iron and manganese oxides and adds somewhat to the induration. This slight, but obvious, lithification appears to be sufficient to prevent winnowing or erosion of the very fine chalky Pliocene sediment under the present conditions of strong water motion that now permits deposition of only a little coarse sand, granule, and gravel-size material. This coarser material with reef debris shows no induration, and stable accumulation in the patchy, thin veneer may be negligible, as much of this is doubtless being shifted across the shelf to deeper water.

The effects of strong water motion on this Quaternary deposition off Eniwetok is thus especially clear. It also seems a clear, although

not unique, example of a marked contrast with the pre-Quaternary deposits, both accumulated here under comparable topographic relations. Some limitation on any possible changes in ice caps. Such difference in the strength of deep water motion is suggested by some other occurrences, showing a similar contrast in character between the Quaternary deposits and

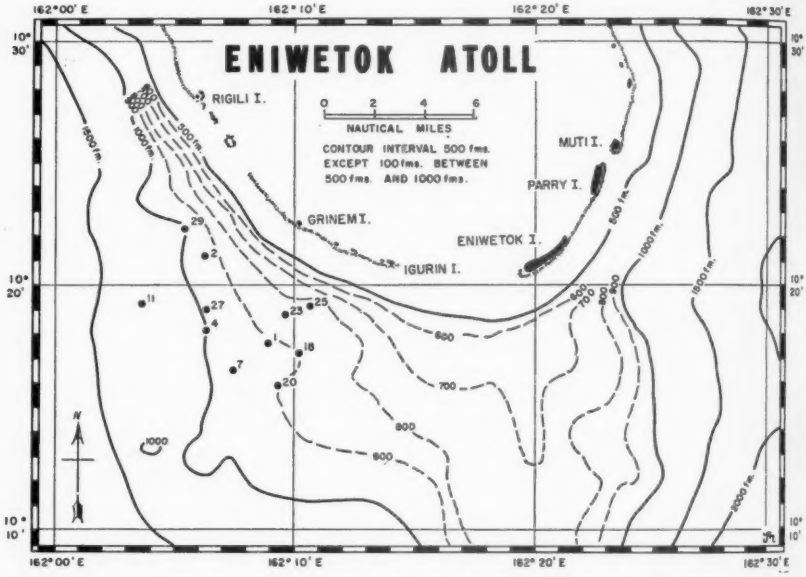

FIGURE 1.—LOCATION OF CORES ON SHELF ON THE SOUTHWEST FLANK OF ENIWETOK ATOLL

water depth here is also indicated by the record of continued coral-reef growth.

Many photographs of ripple marks are now available to supplement other good evidence of considerable bottom-water motion in the modern deposits on guyots, the Mid-Atlantic Ridge, and other topographic highs. Deep currents of adequate strength are now being recognized in the Atlantic, although their pattern and cause are not yet clear (Swallow and Worthington, 1957, p. 1183–1184).

Water motion at a depth of about 1 mile on the terrace bottom seems, however, to have been of no more importance in the late Tertiary sedimentation than was once thought usual in the modern oceans below depths influenced by waves and currents known at the surface. The marked difference in such paleo-oceanographic conditions would not seem probable, although some conditions of the Quaternary oceans, as of the continents, may be rather abnormal as compared with those during much of the earth's history. Strength and pattern of some surface currents may have been modified during the ice age, and perhaps the deeper circulation was equally or more greatly modified by the polar

those of several ages within the Tertiary. These other occurrences, however, have not had the additional evidence indicated by the relations to a drilled coral reef, and the debris from it.

Prior to the recent recognition of the probable strength of deep currents, other possibilities for adequate water motion to produce the observed results included the occasional tsunamis. With this hypothesis, however, the described difference in the sediment records would imply the improbable condition that tsunamis were much less important in pre-Quaternary time.

Evidence for the age assignments will not be presented here but is based largely on the distinctive assemblages of coccoliths, including discoasters and related forms. Differences between the pelagic assemblages of Quaternary and Pliocene Foraminifera are not great and seem to be of little age significance, although the common occurrence of *Globigerinoides sacculifera fistulosa* (Schubert) in the Pliocene here and elsewhere may be significant, as the typical form of the subspecies has not been found in post-Tertiary deposits. The specimen figured in Cushman's textbook (Foraminifera) is designated as Recent, but neither this spec

men nor records of it can now be found, and it is not recorded in his publications on Recent Foraminifera. Microfossils from Tertiary occurring at the ocean's bottom surface and reworked from these "outcrops" are more common than formerly recognized, however, and such a specimen may thus have been found in an otherwise Recent assemblage. Core 20 is evidently older than the others assigned to the Pliocene, as indicated by both the coccoliths and Foraminifera, and may prove to be of late Miocene age, if a differentiation of this from early Pliocene is possible.

This work represents results of research supported, in part, by the Office of Naval Research.

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Scripps Institution of Oceanography, La Jolla, Calif.

Manuscript Received by the Secretary of the Society, June 26, 1959

Contribution from the Scripps Institution of Oceanography, New Series

Brief Notes on Core Samples

(*Globigerina* sand is used for sand-sized sediments composed largely of *Globigerina* and other pelagic Foraminifera, and "ooze" for the very fine-grained sediments. High calcium-carbonate content indicated by four analyses seem representative.)

Core No.	*Length (cm)*	
1	0–21	*Globigerina* sand with some sand-size reef debris (Quaternary)
2	0–20	Reef debris of coarse sand to granule size and *Globigerina* sand (Quaternary)
4	0–61	Slightly indurated *Globigerina*-coccolith "ooze", with brown crust in top 3 cm and decreasing brown mottling down to 10 cm (Pliocene)
7	0–4	*Globigerina* sand with reef debris up to coarse sand size (Quaternary)
11	0–2	Brown volcanic sand with calcite cementation of upper 1 cm. No Foraminifera nor reef debris (age?)
18	0–5	*Globigerina* sand with some reef debris of medium to coarse sand size (Quaternary)
	5–61	Slightly indurated *Globigerina*-coccolith "ooze" with faint brown mottling near top (Pliocene)
20	0–13	Slightly indurated *Globigerina*-coccolith "ooze" ($CaCO_3$ = 95 per cent at 12 cm) with brown crust at top and brown mottling decreasing downward (lower Pliocene or upper Miocene).
23	0–12	*Globigerina* sand with some reef debris of coarse sand size (Quaternary).
	12–66	Slightly indurated *Globigerina*-coccolith "ooze" ($CaCO_3$ = 96 per cent at 30 cm) with brown mottling decreasing downward from 12 to 25 cm (Pliocene)
25	0–46	Reef debris and *Globigerina* sand, with coarser debris up to 4 mm at 4–8 cm and at 15 cm ($CaCO_3$ = 93 per cent at 20 cm) (Quaternary).
27	0–12	*Globigerina* sand with some reef debris (Quaternary)
	12–28	Slightly indurated *Globigerina*-coccolith "ooze", with brown crust at top and brown mottling decreasing downward (Pliocene)
29	0–10	Reef debris of coarse sand size and *Globigerina* sand (Quaternary).

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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AGE MEASUREMENTS ON SOME GRANITES AND GNEISSES FROM THE ALPS

BY EMILIE JÄGER AND HENRY FAUL

The fascinating Alpine complex is the most thoroughly studied of all major upheavals in the earth's crust. Few other areas in the world are the subject of such detailed geologic mapping and so vast a geologic literature. The most recent work summarizing these findings is by Cadisch and Niggli (Cadisch, 1953).

We sampled three geologic units of the Alps: The Aare massif in the Bernese Oberland, the Ticino gneiss in the valley of the Verzasca, and the much studied Baveno granites of Lago Maggiore in northern Italy (Fig. 1; Christ and Nabholz, 1955). These regions were selected primarily because each offers the key to interesting problems of Alpine history. Our choice of localities was governed by the needs of the geologists then working in these areas. Our results are summarized in Tables 1 and 2.

In the perspective of past research on Alpine geology, our study is but a casual glance. We present these numbers not as a quick solution to the manifold problems of Alpine history but more properly as an invitation to much further work that must follow.

All samples were collected (by Faul) in close collaboration with the field geologists currently interested in the areas studied. We gratefully acknowledge the kind assistance in the field of Professor Th. Hügi (University of Bern) in the Haslital; Professor E. Wenk (University of Basel) in the Val Verzasca; and Dr. J. Schilling (now of the Geological Survey Department, British Guiana) in the vicinity of Baveno.

Mineral separations were made in Bern and at the U. S. Geological Survey in Washington. Potassium analyses and preliminary calcium estimates were made with a Perkin-Elmer flame photometer by Paul L. D. Elmore and Wallace W. Brannock (U. S. Geological Survey), argon analyses are by Jäger and Faul, and rubidium and strontium analyses are by Jäger, G. L. Davis, and G. R. Tilton. The mass spectrometers of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, were used in the rubidium and strontium analyses. We are grateful to L. T. Aldrich for his assistance. Professors W. Bucher, H. Eugster, E. Niggli, and E. Wenk critically reviewed the manuscript and made valuable suggestions. The senior author gratefully acknowledges the support of the Schweizerischer Nationalfonds zur Förderung der Wissenschaftlichen Forschung.

Aare Massif

The crystalline *Aare massif*, about 35 km wide and about 115 km long, is generally regarded as a remnant of a Hercynian range which was swept up again in the Alpine orogeny. Several Hercynian and possibly pre-Hercynian granites here intrude older metamorphic series of unknown age. The Tödi granite in the eastern part of the massif is closely bracketed stratigraphically; it intrudes fossiliferous strata of the Westphalien D (Jongmans, 1950), equivalent to Middle Pennsylvanian, and is overlain by Triassic rocks on a weathered Permian surface (H. Widmer, 1949, unpublished dissertation, Univ. Zürich). The general structural setting is well shown on the Geologische Generalkarte der Schweiz, Sheet 3 (Christ and Nabholz, 1950).

The stratigraphic age of the central Aare granite is less clear. It is usually regarded as late Carboniferous or early Permian (Eugster, 1951; Sigrist, 1947). The Mittagfluh granite, roughly in the geometric center of the Aare massif, is considered to be a later marginal intrusion of the central Aare granite (Hügi, 1956), which is the largest granite body of the Aare massif. The Alpine metamorphism is visible in all these rocks. The metamorphism is of sufficiently low grade so that most of the pre-Alpine texture and composition are preserved.

The biotite of the Mittagfluh granite appears to be only slightly altered. Under the microscope we see a gradual transition from a brownish to a greenish mica, especially around inclusions and fractures. The color differences are best seen in very thin flakes. Biotite of the central Aare granite Räterichsboden is heavily altered. The biotite of the Tödi granite is almost completely chloritized, and we failed in our effort to obtain a useful biotite concentrate from this important granite.

Our sample of the Aare granite at Räterichsboden (A2) is a heavily mylonitized medium-

grained white granite. Chains of fine quartz, sericite, and ground-up biotite surround coarsely perthitic and relatively unaltered potassium

the Ticino permits a look at the deepest laye of the crystalline decken that were thrust ov during the main Alpine folding. We find here

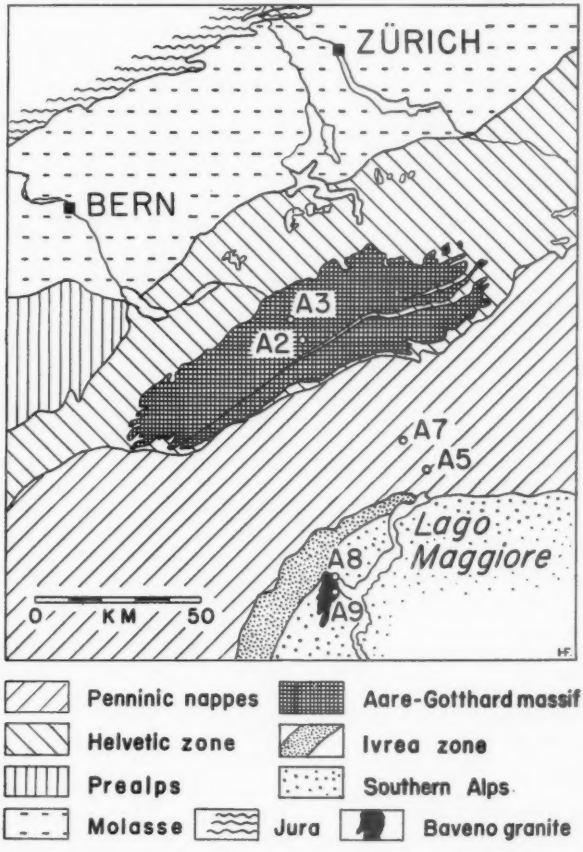

FIGURE 1.—GEOLOGIC SKETCH MAP OF THE CENTRAL ALPS
The numbers refer to our sample localities

feldspar crystals. Plagioclase is badly sericitized. Biotite is uniformly olive green (brownish biotite is not seen), and many grains are bent and torn. Quartz is strained and fractured. The Mittagfluh sample (A3) is similar to A2, but the degree of mylonitization is much less.

Ticino Gneiss

The foliate gneiss (Plattengneiss) and granite gneiss of the Verzasca valley are part of the lower *Penninic nappes* (Lepontine gneiss complex of Wenk, 1956). The regional doming in high grade of metamorphism with compl recrystallization (Wenk, 1948). Wenk's (194 1955) petrofabric studies have shown that mi was recrystallized during the main folding b that quartz recrystallized only after the foldi was essentially complete. Our samples we taken from the gneiss shell (Brione, A7) a from the granitic core (Corippo, A5) of t western part of the Simano decke. According Wenk (1948), both rocks are Alpine in a

The sample from Corippo (A5) is an unalte medium - grained muscovite - biotite - olig

clase gneiss with subordinate amounts of microcline and much sphene. Quartz is strained, but the mica is unusually clean, undisturbed, and has few inclusions. The Brione sample (A7) is a thinly banded and fissile fine-grained muscovite-biotite-oligoclase gneiss with strained quartz and a chemical composition corresponding to trondhjemite. The micas are similar to those of the Corippo sample.

TABLE 1.—AGE RESULTS

Calculated with the following constants:
K^{40}: $\lambda\beta = 4.72 \times 10^{-10}$/y, $\lambda\gamma = 0.585 \times 10^{-10}$/y; $K^{40} = 1.22 \times 10^{-4}$ g/g K.
Rb^{87}: $\lambda = 0.139 \times 10^{-11}$/y; $Rb^{87} = 0.283$ g/g Rb.
All samples are biotite unless otherwise noted. Estimated errors in ages are less than 3 per cent or 2 m.y., whichever is greater. The estimated error in sample A8s is 15 per cent.

Locality	Sample No.	K/Ar age (m.y.)	Rb/Sr age (m.y.)
Baveno			
Mont Orfano	A8	268	290
Mont Orfano, K-spar	A8s		291
Baveno	A9	269	..
Aare massif			
Räterichsboden (Zentraler Aaregranit)	A2	23	..
Tchingelbruücke (Mittagfluhgranit)	A3	75	77
	A3b	78	..
Ticino (Verzasca)			
Brione (Plattengneiss)	A7	18	17
Brione, muscovite	A7m	19	..
Corippo (Granitgneiss)	A5	18	..

Baveno Granites

The body of much analyzed (Smales *et al.*, 1958; Deutsch *et al.*, 1958) granites, which stretches from Mont Orfano on the Lago Maggiore toward Lago d'Orta some 12 km to the south, was considered to be Alpine in age by Staub (1949). Novarese (1933) and Schilling (1957) regard it as probably Hercynian, but the stratigraphic relations are not clear. The age of these granites is of great importance, for it determines the position of the *Ivrea zone* (Fig. 1) in the structure of the Alps.

This zone of basic and ultrabasic rocks within gneisses and schists strikes northeast from Ivrea to Locarno, a distance of about 120 km (Christ and Nabholz, 1955). Gallitelli (1938) and Schilling (1957) describe contacts which show clearly that the Ivrea zone is older than the Mont Orfano granite. If the Ivrea zone were the southernmost of the Alpine roots, then the post-orogenic granites would have to be very young indeed. This was Staub's interpretation and is represented as such on the most widely used maps. If the granite were found to be much older, however, then the Ivrea zone would have to lie entirely outside the body of Alpine orogeny—*i.e.*, south of the "Insubrian Line", as part of the basement complex along the southern slope of the Alps. This is the interpretation shown by Christ and Nabholz (1955).

On the basis of his studies, Schilling (1957) has stated that the Baveno granites are probably Hercynian. We have shown that at Mont Orfano and Baveno the granites are decidedly older than Alpine (Table 1), thus confirming the modern view that the Ivrea zone cannot be regarded as a root of Alpine decken.

Our sample from Mont Orfano (A8) is a medium-coarse white biotite granite, mechanically undamaged. Much biotite is fresh. Chlorite is present but mostly in distinct grains easily separated from the biotite. Plagioclase grains are slightly sericitized. Potassium feldspar is clear and fresh. The rock from Baveno (A9) is similar to the Mont Orfano sample, but pink and more heavily altered. There is sufficient fresh biotite to permit a fairly clean concentrate. However, the potassium content of the final concentrate is low (Table 2).

Results

Beginning with the oldest rocks, we have measured the Mont Orfano granite to be about 290 million years old by the Rb/Sr method. The K/Ar ages of Baveno and Mont Orfano are about 270 m.y.—a difference that could be simply ascribed to argon loss. It is not unusual to find Rb/Sr ages slightly higher than K/Ar ages (Aldrich and Wetherill, 1958, p. 271). Nevertheless, the exact agreement between the K/Ar ages of two samples taken several kilometers apart may imply that all radiogenic argon was lost from these micas 270 million years ago as a result of a gentle regional metamorphism that did not affect the Rb/Sr

ratio. A partial loss of argon at a later time appears less likely.

For the Mittagfluh granite (A3) of the central Alps we find a concordant K/Ar-Rb/Sr age of

a Rb/Sr determination on this highly altered sample (A2).

The results from Val Verzasca leave little doubt that the Penninic nappes were thrust

TABLE 2.—ANALYTICAL RESULTS

Brackets indicate replicate determinations. Letters following the sample number indicate different mica concentrates of the same rock sample. Concentrates for Rb/Sr analysis were the most highly purified. A3b is a coarse (+20 mesh) fraction. A7m is a muscovite, and A8s is a potassium-feldspar concentrate. Estimated errors are less than 2 per cent unless shown otherwise.

No.	K (per cent)	Radiogenic Ar^{40} (ppm)	Radiogenic Ar^{40} / Total Ar^{40}	Rb^{87} (ppm)	Radiogenic Sr^{87} (ppm)	Radiogenic Sr^{87} / Total Sr^{87}
A2	6.37	0.0110	0.26	..	..	..
		0.0099	0.37	..	..	..
A3a	6.51	0.0357	0.40	..	..	..
A3b	5.30	0.0300	0.53	..	..	..
A3c	..	..	..	555	0.593 ± 0.02	0.35
A5a	7.79	0.0102	0.43		..	..
	7.74					
A7a	7.70	0.0100	0.26	..	..	..
A7b	..	..	..	165	0.0386 ± 0.004	0.11
				166	0.0388 ± 0.004	0.08
A7m	6.47	0.00888	0.26	..	..	..
A8a	6.48	0.132	0.94	..	..	..
		0.134	0.72	..	..	..
A8b				233	0.941 ± 0.02	0.76
A8c	6.52	0.135	0.88			
A8s				113	0.457 ± 0.07	0.07
A9	4.22	0.0870	0.82	..	..	..
		0.0871	0.91	..	..	..

about 77 m.y. The concentrate we analyzed was a mixture of greenish and brownish mica. Assuming that the brown mica has remained essentially unaltered since Hercynian time, and the green recrystallized in Alpine time, one would expect such a mixture to give an almost concordant Rb/Sr–K/Ar age somewhere between the Hercynian and the Alpine times. However, until we are able to analyze the two micas separately, we may not ignore the possibility of a complete recrystallization 77 million years ago.

The central Aare granite (A2) contains only olive-green mica and gives a K/Ar age of 23 m.y. This result may indicate that the brown mica of the Mittagfluh granite (A3) is much older than the measured age of that sample (77 m.y.), and that some of this brown mica recrystallized into the green mica at the time of the Alpine orogeny, with an almost complete loss of argon. We have not attempted

and the micas completely recrystallized 18 m.y. ago, thus confirming the views of Wenk (1949) and Niggli (Cadisch, 1953, p. 77), based on petrography and field relations.

Localities

(A2) *Räterichsboden:* New road-cut blasting debris near Räterichsboden Dam, Grimselstrasse. Swiss co-ordinates 667.90/160.65; 46° 35.8′ N. 8° 19.5′ E. of Greenwich.

(A3) *Tchingelbrücke:* Broken blocks of Mittagfluh granite near northwest side of the bridge. 666.05/166.0; 46°38.6′ N., 8°18.0′E. of Greenwich.

(A5) *Corippo:* Old quarry on Verzasca road near Corippo 708.6/122.2, 46°14.59′N., 8°50.84′E. of Greenwich.

(A7) *Brione-Verzasca:* Quarry 50 m north of Ponte Scuro in the valley of the Osola. 703.7/128.2. 46°18.07′ N., 8°47.14′E. of Greenwich.

(A8) *Mont Orfano:* Working quarry 100 m north

no. 105, via 42 Martiri (route 34) near Gravellona, Italy. 45°56.25′N., 4°0.15′W. of Rome.

(A9) *Baveno:* Large working quarry on Mt. Camoscio, about 1 km south of Feriolo near Baveno on Lago Maggiore, Italy. 45°55.2′N., 3°58.5′W. of Rome.

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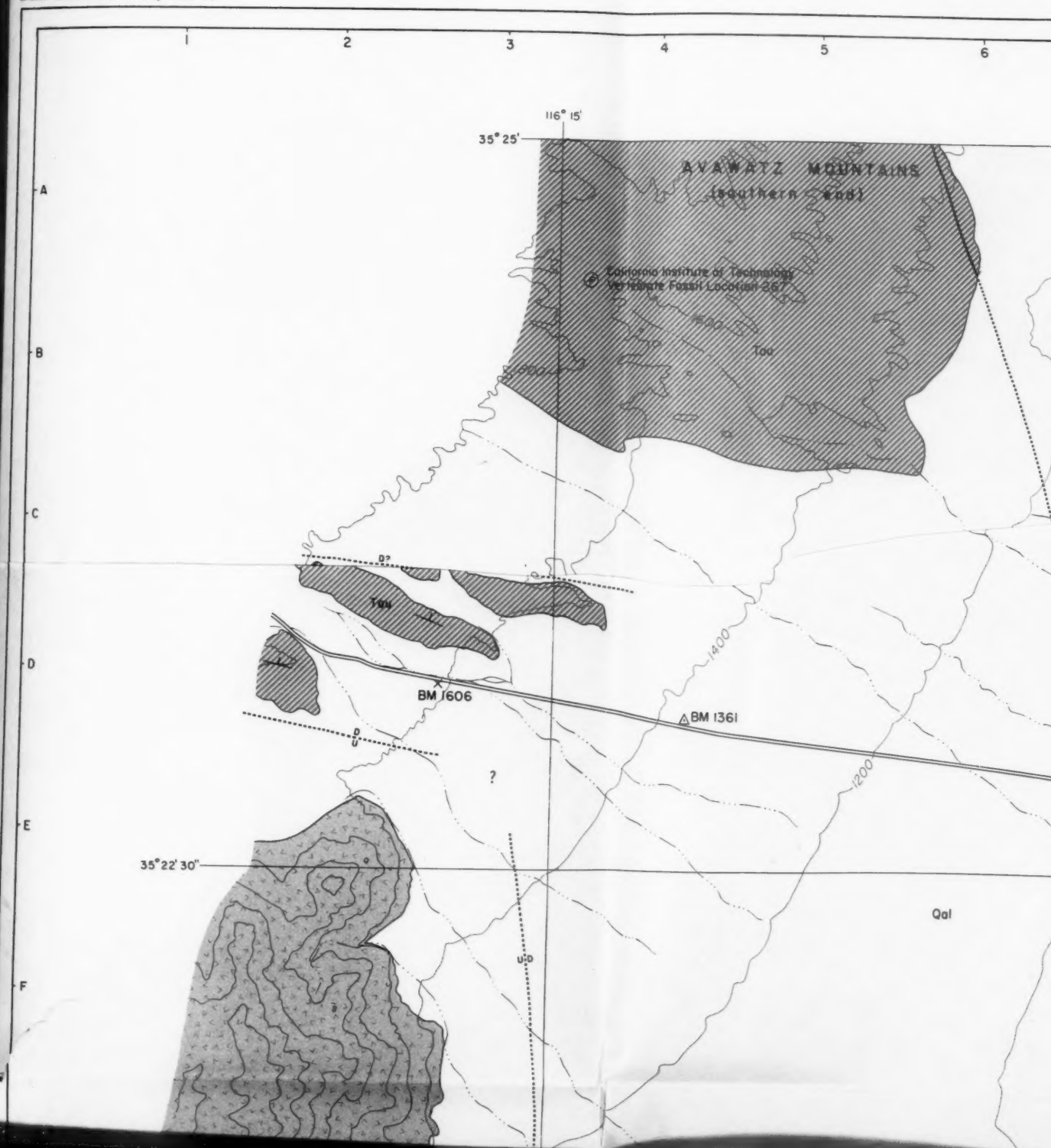
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AVAWATZ MOUNTAINS
(southern end)
California Institute of Technology
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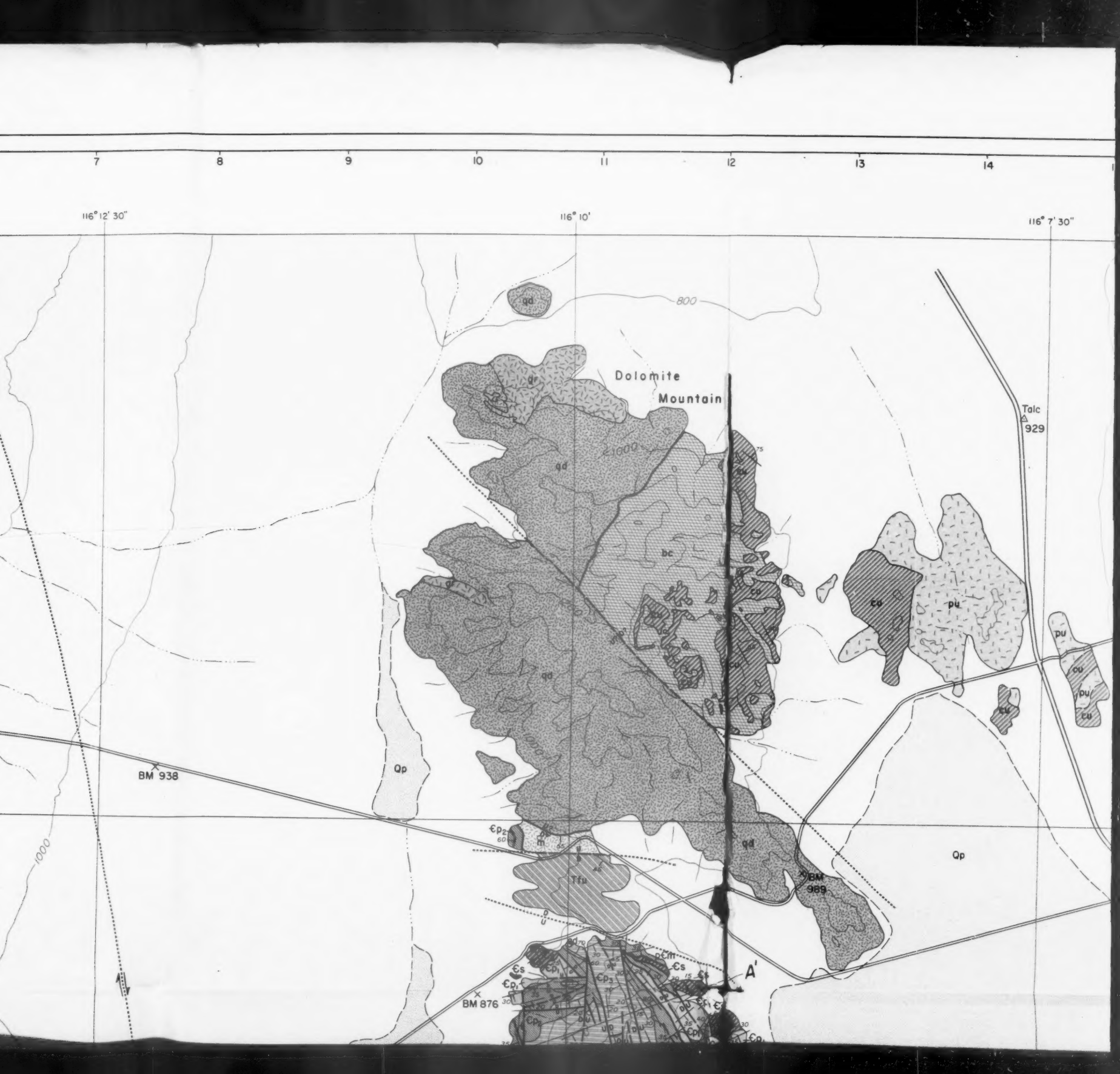
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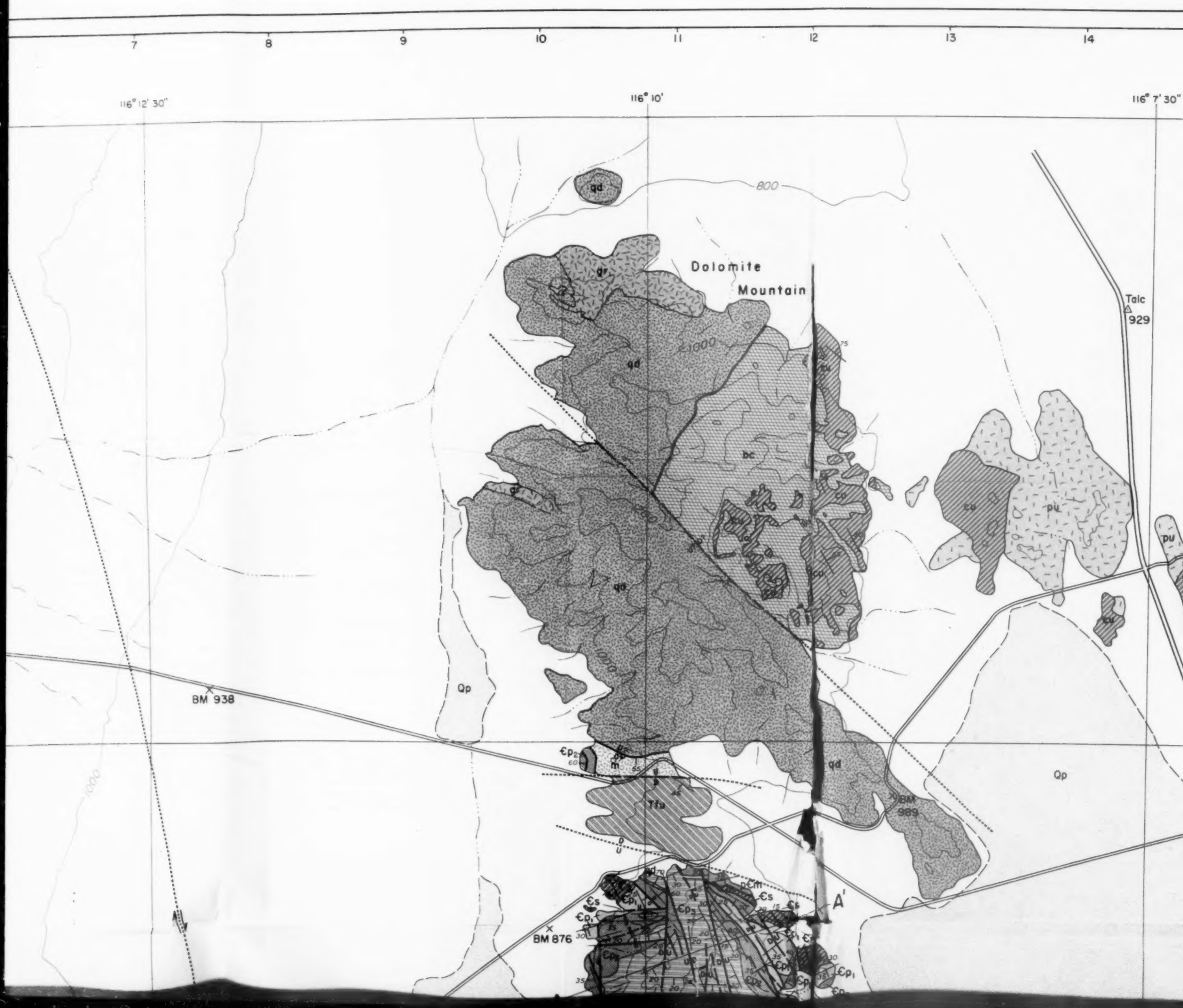
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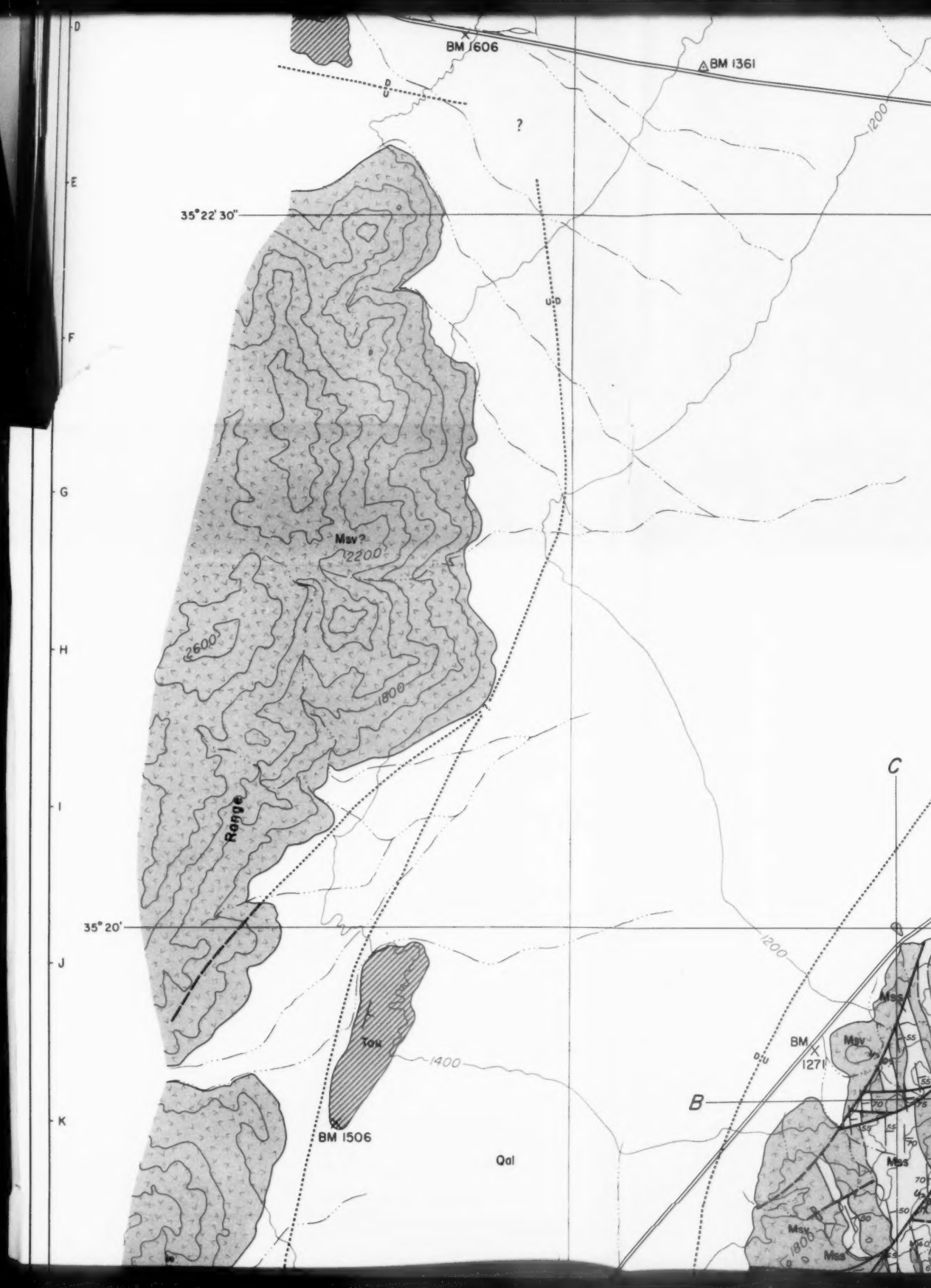
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Lakeshore Hill
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Target
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SODA-AVAWATZ FAULT ZONE
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Granite
Ridge
Soda Mtn
VABM 3437
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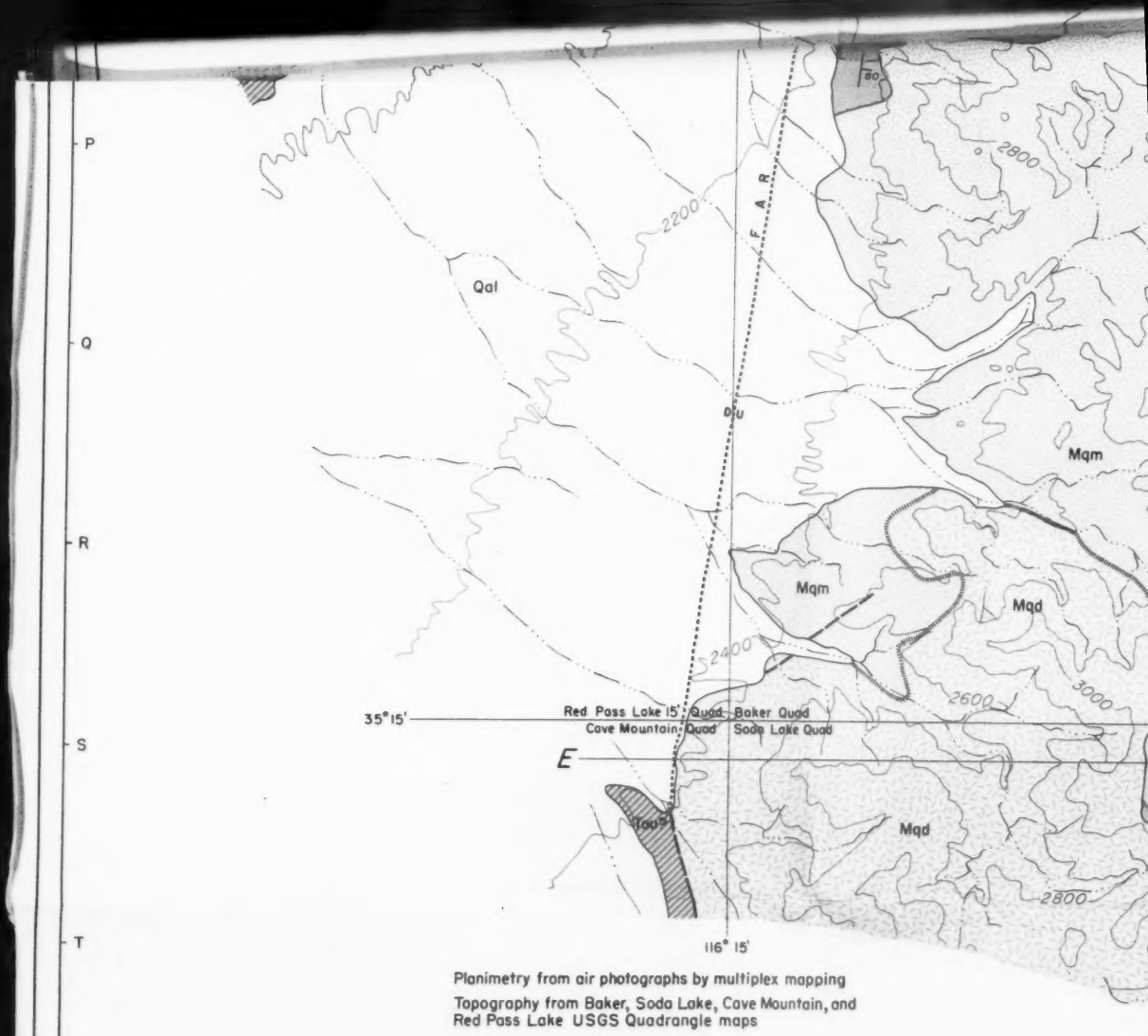


EXPLANATION

QUATERNARY

Qal — Alluvium

Qp — Playa

TERTIARY

LOWER PLIOCENE

AVAWATZ FORMATION

Tag — Gravel, fine, poorly bedded

Tas — Sand and gravel in lenses and beds

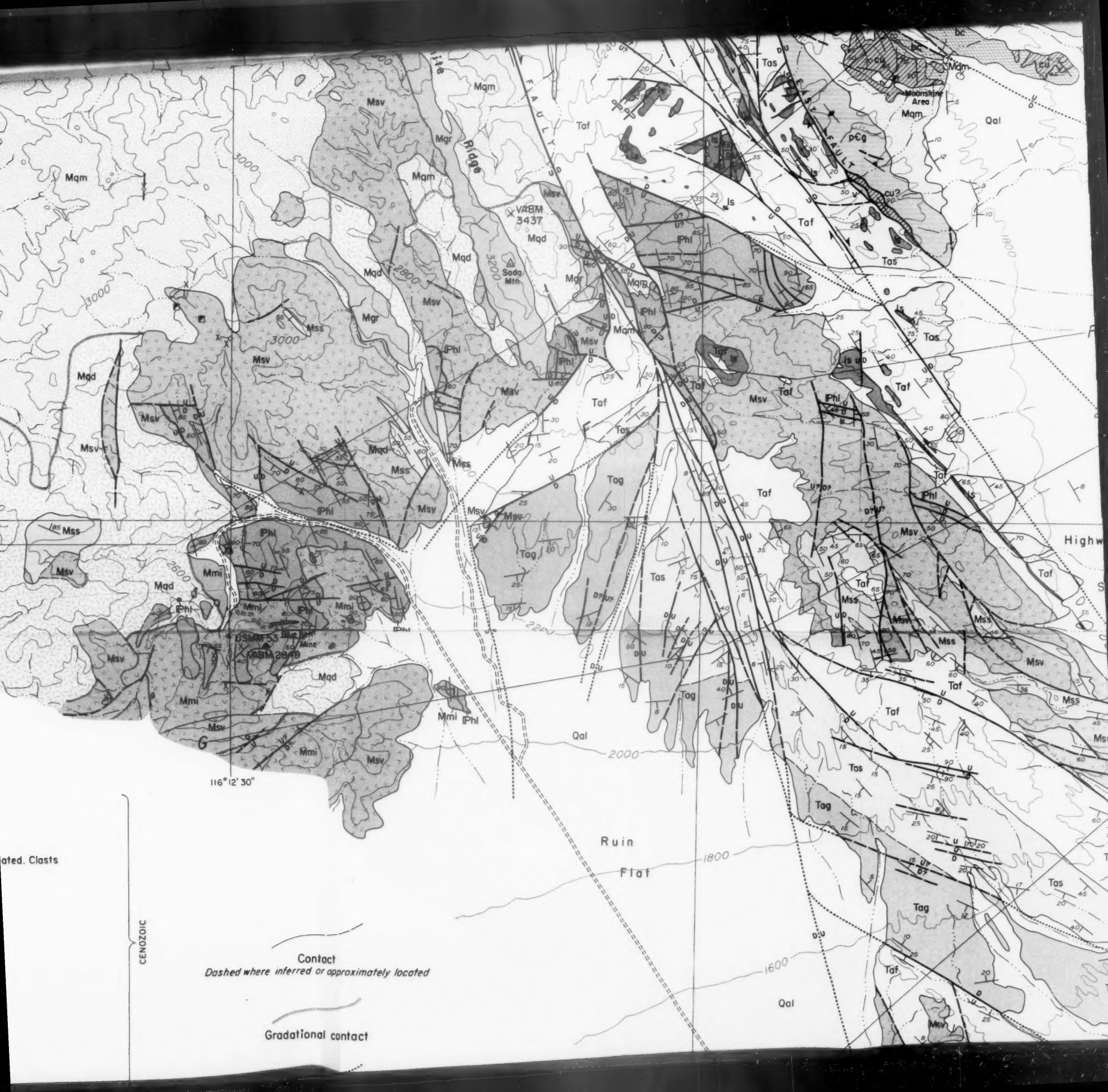
Taf — Fanglomerate, boulder and cobble, poorly bedded

Tfu — Fanglomerate, undifferentiated. C
are mainly plutonics

Tao — Avawatz formation, undifferentiated

ls — Limestone breccia
monolithologic

v — Andesite breccia, monolithologic,
sedimentary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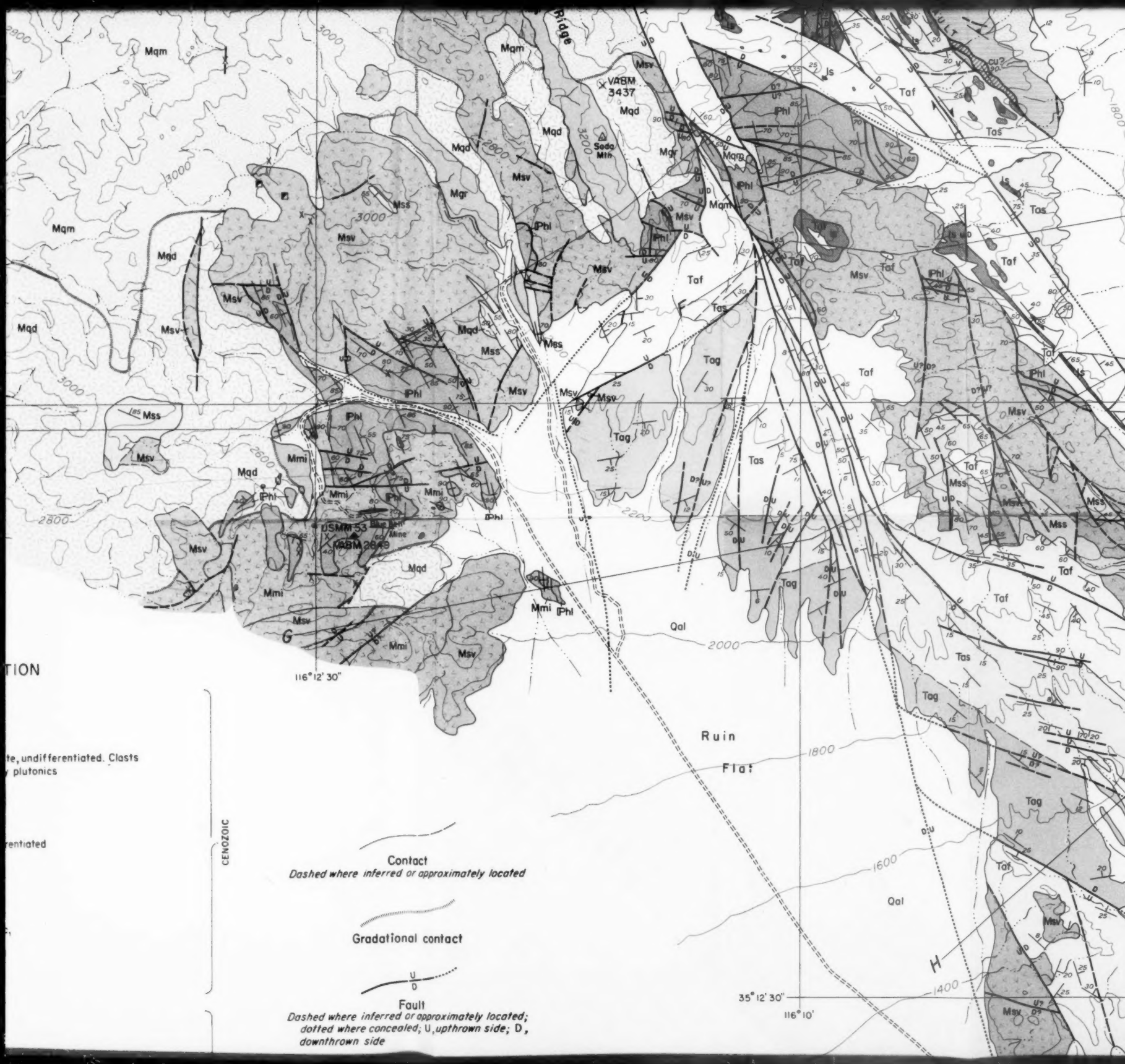
VABM 3437
Mqd
Soda Mtn
Phl
Mss
Taf
Tas
Tag
Qal
Mmi
Moonshine Area
pCg
cu?
ls
USMM 53
Blue Bell Mine
VABM 2849
116°12' 30"
Ruin Flat
Highw
CENOZOIC
Contact
Dashed where inferred or approximately located
Gradational contact
ated. Clasts



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plutonics

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CENOZOIC

Contact
Dashed where inferred or approximately located

Gradational contact

U
D

Fault
Dashed where inferred or approximately located; dotted where concealed; U, upthrown side; D, downthrown side

BAKER
BM 923
Baker Hill
BM 923
Jeep Flat
F'
G'
H'
35°15'
Highway
Spur
Taf
Qal
BM 922
Tas
Msv
Mss
Taf
Msv
Msv
Tas
Taf
Tas
Msv
Is
Msv2
Tag
Taf
91
BM 924
Tidewater
VABM 1153
Mqm
Qal
Taf
Msv
35°12'30"
gr
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gd
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1800
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1200
1000

TERTIARY

LOWER PLIOCENE

Tas — Sand and gravel in lenses and beds

Taa — Avawatz formation, undifferentiated

Taf — Fanglomerate, boulder and cobble, poorly bedded

Tls — Limestone breccia monolithologic

Tv — Andesite breccia, monolithologic, sedimentary

W

Tf — Felsite and felsite porphyry; dikes and plugs

LATE MESOZOIC PLUTONICS

X

CRETACEOUS

Mmi — Altered granitic rocks, light gray, silicified, epidotized, brecciated

Mgr — Granite with pinkish K-feldspar, coarse-grained, in part aplitic

Mqm — TEUTONIA QUARTZ MONZONITE and granodiorite, medium-grained, pinkish gray

Y

Mqd — Quartz diorite and diorite, dark gray, fine to medium-grained, in part slightly migmatitic

PRE-TERTIARY PLUTONICS

gr — Microcline granite, white, mediu coarse-grained, uniform

gd — Granodiorite, light gray, medium grained

m — Migmatite, small to large scal mixture of pre-Tertiary plut

pgd — Porphyritic granodiorite, medi gray, with fine-grained ground

qd — Quartz diorite, dark gray, fine grained

bc — Basic complex of gabbroic and gneisses with locally more acid

pu — Pre-Tertiary plutonics, undiffer

SODA MOUNTAIN FORMATION

TRIASSIC-JURASSIC?

Mss — Quartzite, sandstone and minor pyroclastics, yellow, gray, red, fine to very coarse

Msv — Meta-andesite flow breccia and minor pyroclastics, purple, gray, green, epidotized

LOWER TRIASSIC

Ts — Limestone, gray, and shale, red and gray, fossiliferous grading up into red siltstone and sandstone

CONTACT NOT EXPOSED

LOWER PERMIAN

Pbs — BIRD SPRING FORMATION, limestone, gray, thin to thick bedded, fossiliferous, cherty

THRUST FAULT

MISSISSIPPIAN-PENNSYLVANIAN?

PMl — Limestone, gray, interbedded with banded hornfels (meta-marl) and subordinate quartzite

Mls — Limestone, white to gray, massive to thin bedded, locally cherty and dolomitic

CONTACT NOT EXPOSED

PRE-MESOZOIC METASEDIMENT

Cu — Carbonate, undifferentiated. Irr bedded buff dolomite and ligh

LOWER CAMBRIAN?

PROSPECT MOUNTAIN QUARTZITE

$\mathcal{C}p_3$ — Quartzite, dark gray, finely laminated, cross-bedded, medium to very coarse, impure

$\mathcal{C}p_2$ — Quartzite, white, thick bedded, medium-grained to conglomeratic, relatively pure

$\mathcal{C}p_1$ — Quartzite, dark gray, silty; interbedded with dolomite; siliceous

$\mathcal{C}_c$ — Limestone and dolomite, white, gray, buff, crystalline, locally breccia; interbedded with quartzite

CENOZOIC

MESOZOIC

PALEOZOIC

medium to

edium-

e scale directionless
y plutonic types

medium to dark
groundmass

fine to medium-

ic and dioritic
e acidic migmatites

differentiated

ed. Irregular and inter-
d light limestone

Contact
Dashed where inferred or approximately located

Gradational contact

Fault
Dashed where inferred or approximately located; dotted where concealed; U, upthrown side; D, downthrown side

Fault, showing dip

Vertical fault

Fault, showing lateral displacement

Thrust fault
T, *upper plate*

Strike and dip of beds

Strike and dip of overturned beds

Strike of vertical beds

Horizontal beds

Strike and dip of foliation

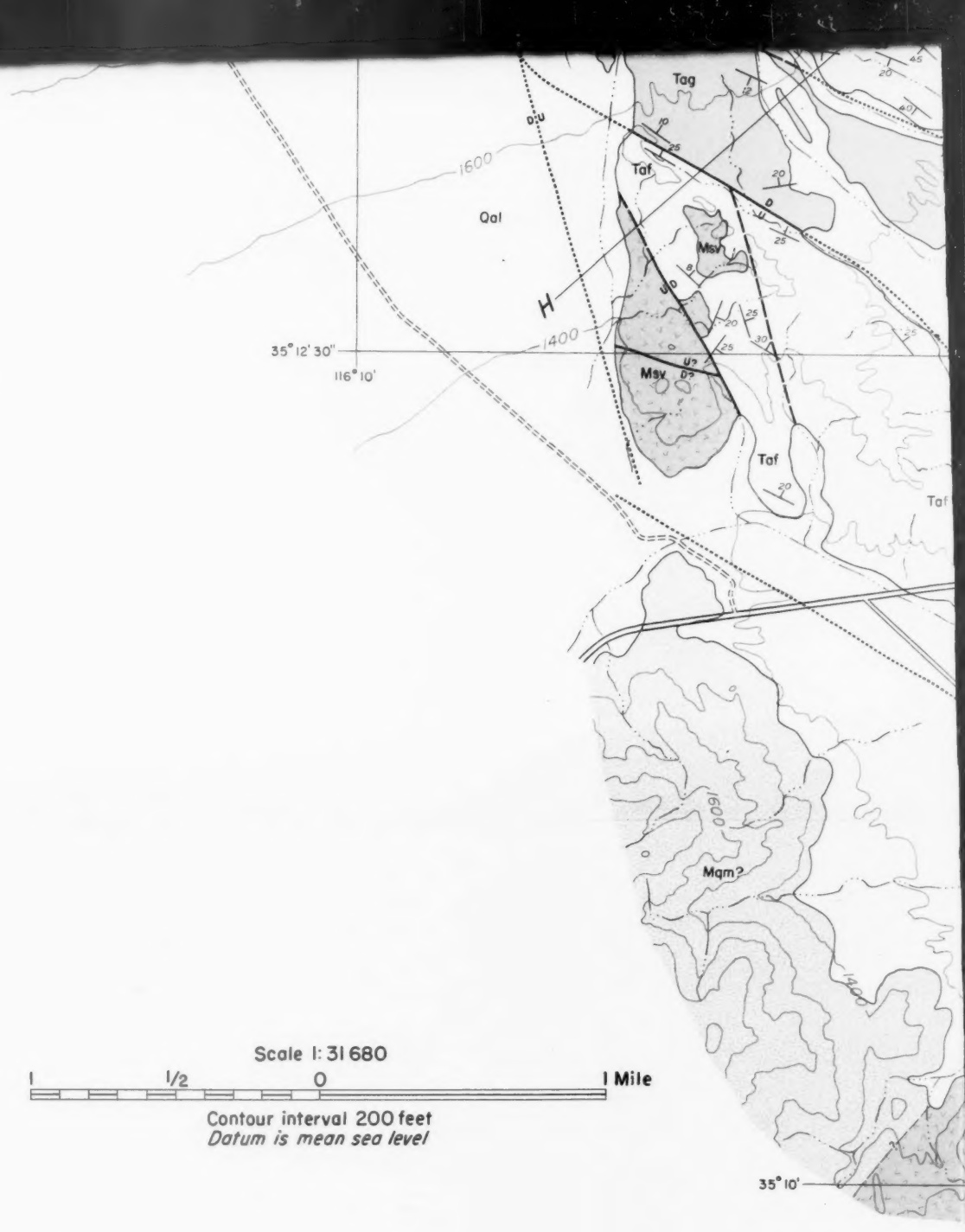
Strike of vertical foliation

Prevailing strike and dip of beds and foliation

Vertical shaft

Adit

X

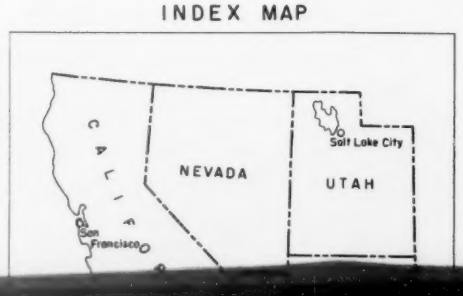


Scale 1: 31 680

1 1/2 0 1 Mile

Contour interval 200 feet
Datum is mean sea level

INDEX MAP



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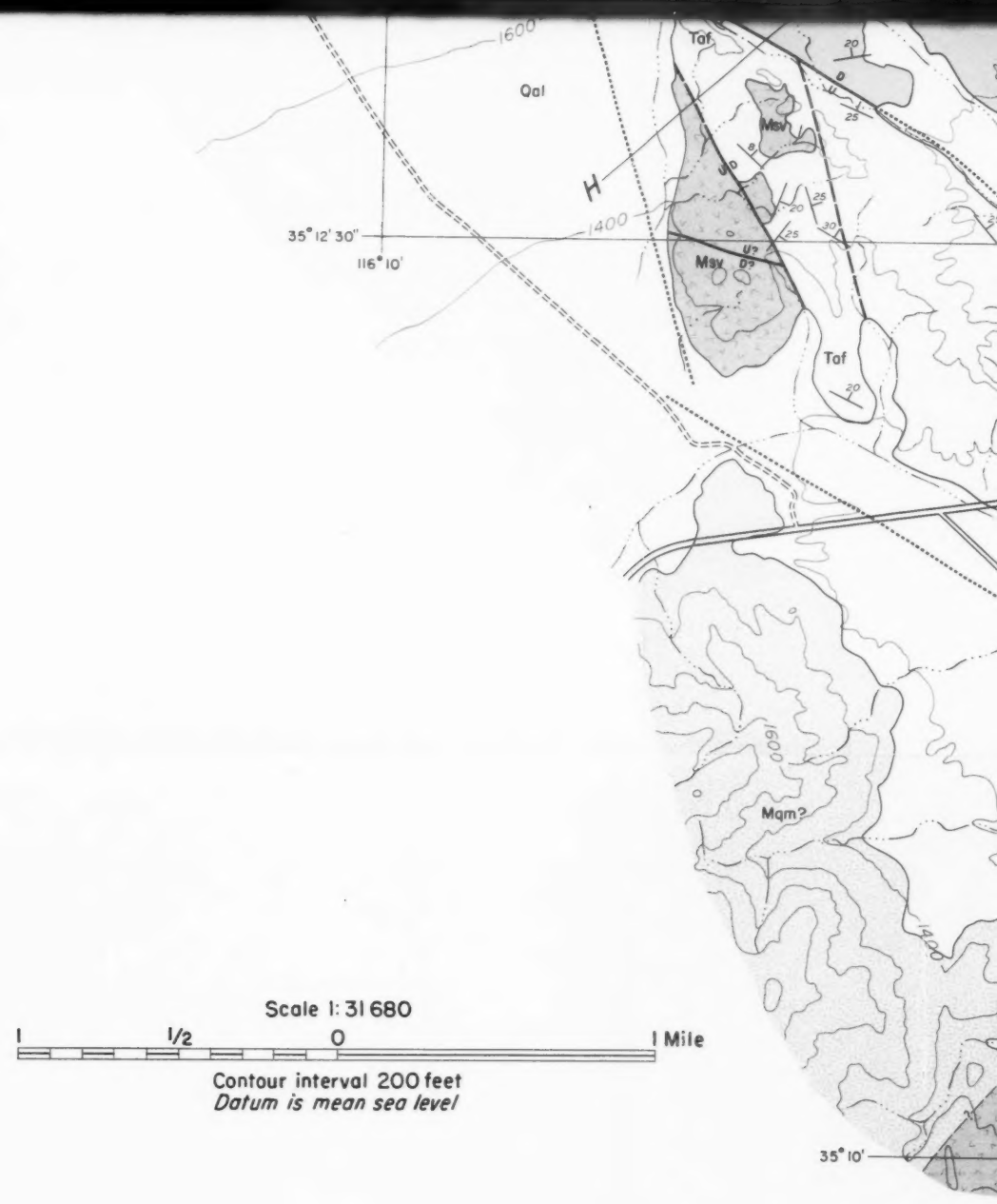

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Contour interval 200 feet
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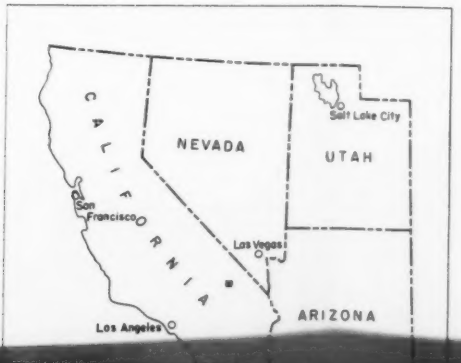

Tag
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Tidewater
VABM 1153
Mqm
Qal
35°12' 30"
Taf
Msv
Taf
Is?
Qp
Mqm
Qal
BM 932
SODA
LAKE
Msv
Zzyzx
Hill
VABM 2266
Soda
35°10'
PLAYA
116°7' 30"
Qp
Mls
Msv
Mls
BM 930

TRIAS-JURAS

Msv — Meta-andesite flow breccia and minor pyroclastics, purple, gray, green, epidotized

LOWER TRIASSIC

T_{Rs} — Limestone, gray, and shale, red and gray, fossiliferous grading up into red siltstone and sandstone

CONTACT NOT EXPOSED

LOWER PERMIAN

Pbs — BIRD SPRING FORMATION, limestone, gray, thin to thick bedded, fossiliferous, cherty

THRUST FAULT

MISSISSIPPIAN-PENNSYLVANIAN?

Phl — Limestone, gray, interbedded with banded hornfels (meta-marl) and subordinate quartzite

Mls — Limestone, white to gray, massive to thin bedded, locally cherty and dolomitic

CONTACT NOT EXPOSED

LOWER CAMBRIAN?

PROSPECT MOUNTAIN QUARTZITE

ϵp_3 — Quartzite, dark gray, finely laminated, cross-bedded, medium to very coarse, impure

ϵp_2 — Quartzite, white, thick bedded, medium-grained to conglomeratic, relatively pure

ϵp_1 — Quartzite, dark gray, silty; interbedded with dolomite; siliceous

ϵ_s — Limestone and dolomite, white, gray, buff, crystalline, locally breccia; interbedded with quartzite

THRUST FAULT

PRECAMBRIAN?

p€m — Metasediment, mainly dark gray quartzite interbedded with calc-silicate layers

p€g — Gneissic complex of fine-grained paragneisses, schists, aplites, quartzites, and local migmatites and granitics

gg — grained

bc — Basic complex of gabbroic and dioritic gneisses with locally more acidic migmati

pu — Pre-Tertiary plutonics, undifferentiated

PRE-MESOZOIC METASEDIMENT

ϵ_u — Carbonate, undifferentiated. Irregular and bedded buff dolomite and light limeston

GEOLOGIC MAP OF T

ritic
igmatites

ated

ar and inter-
estone

PALEOZOIC

PRECAMBRIAN

Strike and dip of beds

Strike and dip of overturned beds

Strike of vertical beds

Horizontal beds

Strike and dip of foliation

Strike of vertical foliation

Prevailing strike and dip of beds and foliation

Vertical shaft

Adit

Prospect pit

Fossil locality

Scale 1: 31 680

1 1/2 0 1 Mile

Contour interval 200 feet
Datum is mean sea level

INDEX MAP

116°

TRUE NORTH

APPROXIMA
DECLINATI

F THE NORTHEAST PART OF THE SODA MOUNTAINS, SAN BERNARDINO COUNTY, CA

p of beds

verturned beds

lical beds

l beds

of foliation

cal foliation

of beds and foliation

shaft

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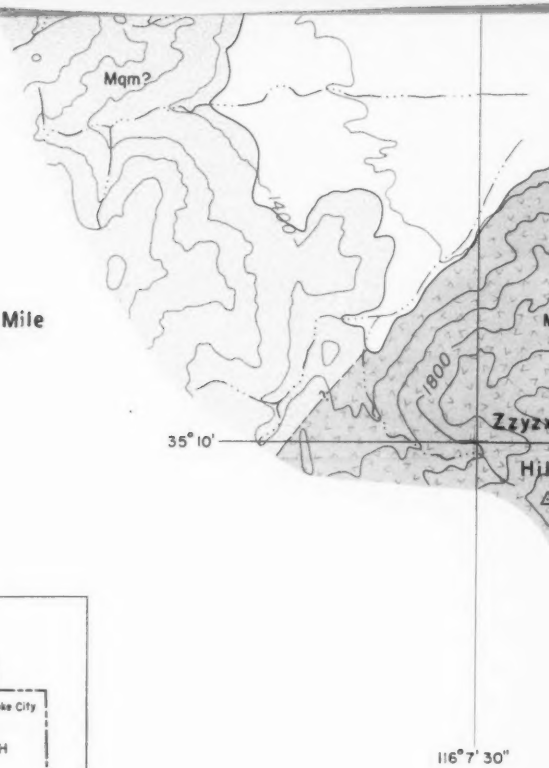
ct pit

ocality

Scale 1: 31 680

1 1/2 0 1 Mile

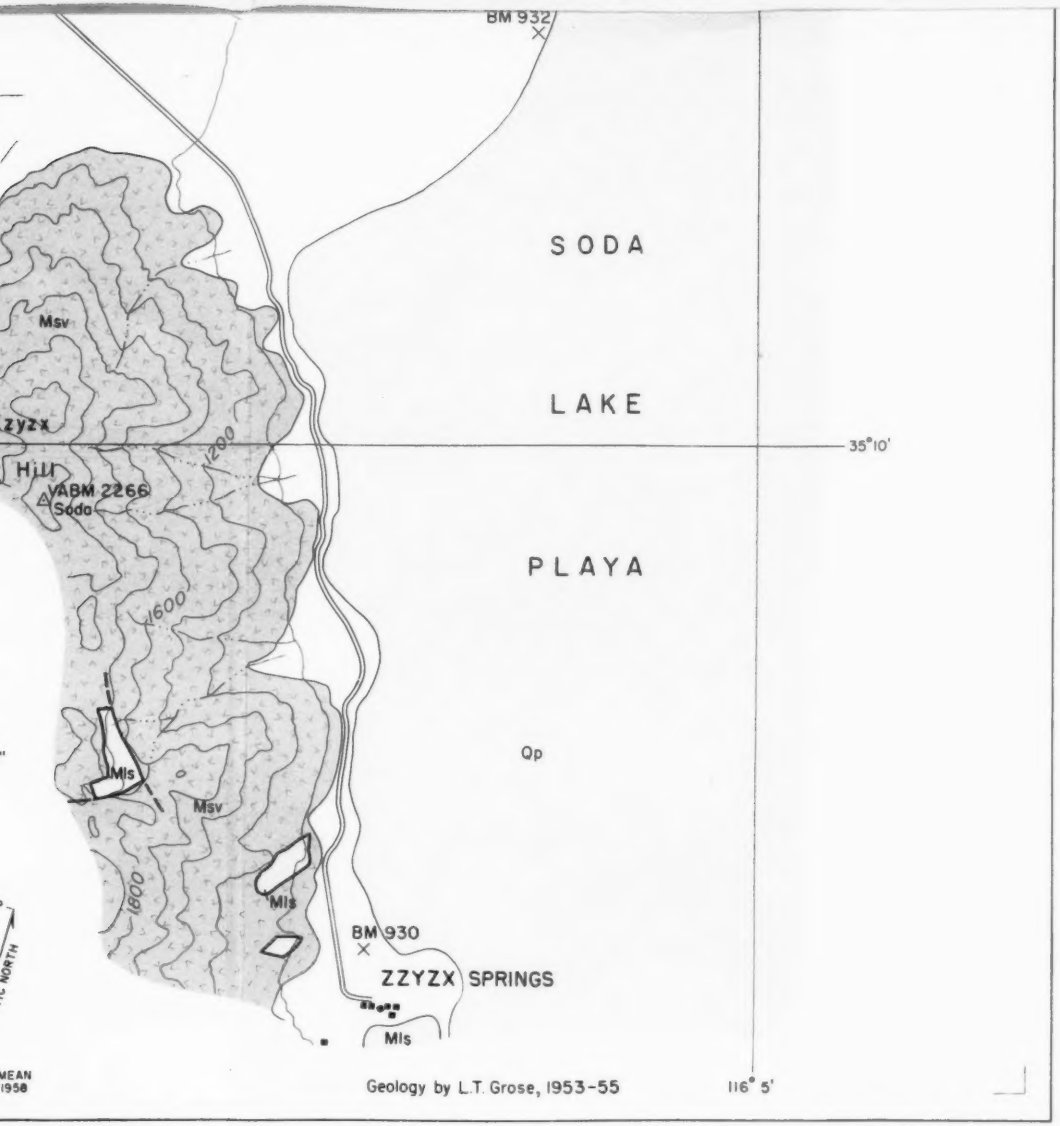
Contour interval 200 feet
Datum is mean sea level



INDEX MAP

APPROXIMATE MEAN DECLINATION, 1958

PART OF THE SODA MOUNTAINS, SAN BERNARDINO COUNTY, CALIF


BM 932
SODA
LAKE
PLAYA
35°10'
Msv
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Hill
VABM 2266
Soda
1200
1600
1800
Qp
Mls
Msv
Mls
BM 930
ZZYZX SPRINGS
Mls
Geology by L.T. Grose, 1953-55
116° 5'

LIFORNIA

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In

Bulletin
of
The Geological Society of America

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PAPERS IN PRESS FOR FORTHCOMING ISSUES

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THRUST FAULTING AND CHAOS STRUCTURE, SILURIAN HILLS, SAN BERNARDINO COUNTY, CALIFORNIA. By Donald H. Kupfer

CARIBBEAN RESEARCH PROJECT: PROGRESS REPORT. By H. H. Hess

GEOLOGY OF THE LA VICTORIA AREA, ARAGUA, VENEZUELA. By J. C. MacLachlan, Reginald Shagam and H. H. Hess

GEOLOGY OF CENTRAL ARAGUA, VENEZUELA. By Reginald Shagam

HIGH-TEMPERATURE ALPINE-TYPE PERIDOTITE FROM VENEZUELA. By D. B. MacKenzie

GEOLOGY OF THE MAYAGUEZ AREA, PUERTO RICO. By Peter H. Mattson

ABSTRACTS OF PAPERS SUBMITTED FOR THE MEETING IN PITTSBURGH, PENNSYLVANIA, NOVEMBER 2-4, 1959

BASAL CHINLE SILICIFICATION

A. M. Abdel-Gawad and Paul F. Kerr
Department of Geology, Columbia University, New York, N. Y.

The base of the Chinle formation on the Colorado Plateau exhibits the activity of silica-bearing solutions. Local silicification may be observed in a number of places associated with argillic alteration, bleaching, dolomitization, and uranium mineralization.

In the San Rafael Swell chert occurs as thin layers, veins, and masses infiltrating siltstones, mudstones, and sandstones. A green-gray bleached halo borders the chert and is characterized by the removal of iron. Silica deposition took place in at least two surges. In each fibrous and spherulitic quartz was deposited followed by cryptocrystalline quartz, and finally druzy crystals formed. The final surge was associated with sulfide and uranium mineralization. Pyrite, marcasite, chalcopyrite, bornite, sphalerite, uraninite, covellite, calcite, dolomite, barite, and coffinite-bearing asphaltite are associated with the silica. Incipient silicification is noted in the dolomitized zones where euhedral prismatic quartz crystals replace the carbonates.

Near Cameron, Arizona, jasper layers occur in a zone characterized by intense bleaching and silicification of the basal Chinle-Shinarump contact.

Silicified "pipes" and quartz masses occur in mottled and bleached basal Chinle outcrops at a point 11 miles east of Moab, Utah.

Silicification is attributed to hydrothermal activity. Hydrothermal solutions carrying silica in amounts above the equilibrium concentration deposited silica in colloidal form. The well-crystallized quartz was deposited from the resultant less concentrated solutions.

STABILITY OF THE NORTH PORTAL AREA OF THE FORT PITT TUNNEL, PITTSBURGH, PENNSYLVANIA

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Landslides in the soil mantle and weathered rock zone in the North Portal area of the Fort Pitt Tunnel threatened the project. The north portal is located about one-third of the way up the steep slope of Mt. Washington, above the Monongahela River, a few hundred feet upstream from the junction with the Allegheny River. The rocks are shales, indurated clays, siltstones, sandstones, limestones, and coals of the Monongahela and Conemaugh series (Pennsylvanian). It is a region of gentle synclines and anticlines. Excavations for the ventilation building and emergency ramp area required deep cuts adjacent to the remnants of two major landslides. Near the portal, the twin 35-foot wide vehicular tubes intercepted a number of open sheeting joints up to 6 inches in width. Exploration indicated the depth of primary weathering is about 20–30 feet. The major sheeting joints had a dip of about 77° with a strike parallel to the river. Stability analysis was carried out using the circular-arc method and average rock strengths from local landslides. Seven benches were created and waterproofed by bituminous coating. Horizontal drains 6 inches in diameter were drilled up to 300 feet into the hill on 50-foot centers at three elevations to reduce seepage pressures on the cut face.

ENVIRONMENT OF DEPOSITION OF THE LOWER TERTIARY FORMATIONS IN NEW JERSEY

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In New Jersey lower Tertiary sediments are divided into the Hornerstown marl, Vincentown sand, Manasquan marl, and Shark River marl.

The Hornerstown marl is a greensand which ranges from a sand to a sandy clay. It is one of the richest beds of glauconite in the world. The Vincentown is divisible into a quartz-sand facies and a limy facies, which change abruptly into each other. The Manasquan marl ranges from a silty sand to a clayey sand and is composed of a mixture of quartz and glauconite. The Shark River marl supposedly overlies the Manasquan as far as this writer can determine, but it has not been observed since 1882. This writer spent several days in the area mapped as Shark River but found no lithologic unit which could be identified as the Shark River marl.

The texture, minerals, and microfossils of the Hornerstown, Vincentown, and Manasquan formations suggest deposition in relatively shallow marine waters. Tidal currents distributed the sediment. Reducing conditions prevailed in the bottom sediments during deposition of the Hornerstown formation and locally during deposition of the Vincentown and Manasquan formations. The Vincentown formation may have been deposited in a shallow bay, the center of which contained a cosmopolitan benthonic community.

The principal source area for the lower Tertiary formations of New Jersey was the exposed portion of the marine Cretaceous formations of the northern Atlantic Coastal Plain. An additional source area may have been the Piedmont Province and possibly the Appalachian Mountains.

CLAY-MINERAL ENVIRONMENTS IN NEW ENGLAND AND EASTERN CANADA

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Clay minerals from 56 samples of shales and clays in New England and eastern Canada were studied by petrographic and X-ray methods to determine if clay minerals could be used as indicators of specific environments of deposition. The potassium clay minerals illite or hydrous mica are the principal clay minerals, and chlorite, or vermiculite, are minor minerals in marine shales and clays, in varved clays of nonmarine origin, and in glacial tills; therefore, they are not characteristic of one environment of deposition. Mixed-layer clay minerals and montmorillonite minerals are not present in sufficient amounts in these samples to be helpful in limiting the conditions of deposition. Sedimentary clays and shales that contain abundant kaolinite were apparently deposited under nonmarine conditions. They were eroded from residual kaolinite clays formed by surface weathering or by hydrothermal replacement and were similar to the kaolinite deposits that occur in this region and are attributed to these processes. It is concluded that the source material had a greater influence on clay-mineral composition than did the environment in which the clay minerals were deposited.

AGE OF PRECAMBRIAN IGNEOUS ROCKS OF MISSOURI

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Determination of age values of five micas by the A^{40}/K^{40} method in the laboratories of MIT

indicates that the mica-bearing basement rocks in which they occur in Missouri are Precambrian. Muscovite from xenoliths in granite at the Elephant Rocks and at a quarry at Graniteville, Missouri, gave age values of 1200, 1210, and 1220 m.y. Biotite separated from a drill core obtained by St. Joseph Lead Co. at depths from 1873 to 2140 feet below the surface, 12 miles southeast of Lebanon, Laclede County, Missouri, gave an age value of 1150 m.y. for a biotite diorite. Zinnwildite sheets, ½ to 1½ inches, obtained from veins cutting the country rock at Silver Mine, Missouri, gave an age value of 1350 m.y. It must be understood that these values represent minimum ages only, as argon will diffuse out of mica structures at elevated temperatures.

CAYUGAN OF EASTERN UNITED STATES

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A composite study of the Cayugan rocks of New York, Pennsylvania, West Virginia, Maryland, Ohio, Indiana, Michigan, and Ontario shows that the Salina salt-bearing beds (salt span) are continuous between two major, interconnected basins. Their stratigraphic relationships are summarized as follows:

WESTERN SALT BASIN	EASTERN SALT BASIN		
Mich.-Ontario	Ohio	W. New York	Pa.-Maryland
Bass Island Gp:	Bass Island Gp:	Manlius-Roundout	Keyser
Raisin River	Raisin River	Cobleskill-Akron	Tonoloway
Put-in-Bay	Put-in-Bay	Salina Gp: Bertie	
Salina Gp: G F E D C B	Salina Gp: Tymochtee ?	Camillus Syracuse	Willis Creek
A	Greenfield	Vernon	Bloomsburg

The Michigan Basin and the Ohio Basin are alike in that evaporites were deposited inside a fringing barrier-reef system of the Guelph-Lockport. The New York-Pennsylvania evaporites were deposited in a basin east of the reef zone and west of the landmass supplying the Vernon-Bloomsburg delta, at the northern end of the Wills Creek-Tonoloway sea.

TIME CRITERIA IN ORE GENESIS: A REVISION

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Observations of past geological processes render usually only data of space (S) and composition (C). Time (T) concepts require interpretations based on geometric (Δs) and geochemical differences (Δc). Time differences (Δt) are thus "frozen into the rock" as Δs, Δc, and $\frac{\Delta c}{\Delta s}$ values. The expressions $\frac{\Delta s}{\Delta t}, \frac{\Delta c}{\Delta t}$, and $\frac{\partial^2 c}{\partial s \partial t}$ are thus normally interpretations and may be zero or near zero (syngenetic formations) or of a certain value (epigenetic formations).

With this in mind, a revision led to the following suggestions: (1) Certain criteria currently used include assumptions of $\frac{\Delta c}{\Delta t}$ and $\frac{\Delta s}{\Delta t}$ which are not justified. (2) It is probably not possible to avoid a basic revision of the present genetic terminology. It may require a liberation of certain terms such as zoning, hydrothermal, replacement, etc., from the epigenetic meaning obtained during a period which favored an epigenetic introduction of material as the main ore-forming process; and the introduction of some purely descriptive, international classification of rock textures and mineral intergrowths. (3) A syngenetic interpretation requires usually less than half the number of assumptions required for an epigenetic theory. (4) Sedimentary petrology is at least as important in ore genesis as igneous petrology. (5) An integration of old and new geometric and geochemical evidences may lead to the following classification of mineral deposits: Except for transitional types, most deposits in sediments are of sedimentary and most deposits in igneous rocks of igneous origin. Syngenetic and consanguineous formation is the rule, epigenetic metasomatism the exception; the latter is practically always restricted to marginal crosscutting zones and veins.

DETAILED X-RAY DATA ON MULLITES AND TWO NEW ANHYDROUS ALUMINOSILICATES AS(H)-II AND HIGH-TEMPERATURE SILLIMANITE

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Synthetic mullites have been prepared from various chemically pure compositions in the Al_2O_3-SiO_2 system from 1800°C. at 1 bar to 600°C. and 5000 bars.

The determination of the lattice constants of some two dozen samples by precise measurements with an internal silicon standard shows the following:

(1) The lattice constants vary with heat treatment almost as much as they vary with solid solution. Hence composition and lattice constant cannot be correlated simply.

(2) There is much evidence from the phase assemblages and X-ray data that there is no solid solution of SiO_2 in mullite from solidus temperatures to about 1000°C. where runs at the 55 and 58 mole per cent compositions yield mullite with sufficient tridymite for detection by powder diffraction.

(3) Many of our synthetic sillimanites (prepared at pressures $>$ 20,000 bars) fall clearly in the sillimanite group but are not identical with natural sillimanites.

(4) Even at hydrothermal pressures between 2000 and 4000 bars the mullites produced are clearly mullites and not intermediate between mullite and sillimanite.

Of the new phases, one has previously been referred to as andalusite. It is actually a new alumi-

nosilicate AS(H)-II possibly having the same relation to andalusite as mullite has to sillimanite. Its unit-cell dimensions are $a = 7.55$Å, $b = 8.27$Å, $c = 5.66$Å, and it has refractive indices $\alpha = 1.625$ and $\gamma = 1.640$. The other new phase, found in a xenolith from the Asama Volcano, Japan, is a modified sillimanite with a much larger c-axis (5.797 *vs* 5.769) than metamorphic sillimanites. Whole families of ordered and disordered phases analogous to the feldspars thus appear to be confirmed for the aluminosilicates.

REVISION OF THE Al_2O_3-SiO_2 DIAGRAM

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On the basis of standard quenching experiments in sealed noble-metal containers up to 1860°C. and high water-pressure runs at low temperatures, the following revisions have been made in the generally accepted equilibria diagram for Al_2O_3-SiO_2.

Mullite melts congruently at 1850°C., and the eutectic between mullite and corundum is at 1840°C., 67 mole per cent Al_2O_3, presenting an extremely flat liquidus in the region from 40 to 67 mole per cent. Equilibrium solubility in mullite extends from 60 to 63 mole per cent. Metastable mullites with about 67 mole per cent Al_2O_3 can be easily crystallized, although only from a liquid phase. True glasses have been prepared to 60 mole per cent Al_2O_3, and their refractive indices vary linearly from 1.459 to 1.597. Our data suggest slight modification of the liquidus profile but appear to confirm the composition of Bowen and Greig's eutectic rather than Trömel's. Excellent confirmation of the congruency of mullite melting has been obtained in the systems MgO-Al_2O_3-SiO_2 and CaO-Al_2O_3-SiO_2.

POTASSIUM-ARGON DATING OF SILICATES USING NEUTRON ACTIVATION FOR ARGON DETERMINATION

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A method for determining the argon content of silicate rocks and minerals by neutron activation has been developed. The argon is released from the specimen by fusion in an induction furnace, after which it is purified over copper oxide and titanium and sealed into a quartz vial. Sample and standard vials are then irradiated for 4 days in the Brookhaven reactor in a flux of approximately 10^{13} n/cm.^{2} sec. Within 6 hours after removal from the pile the gas is purified in the presence of a hydrogen-argon carrier by reaction with copper oxide and condensation of all volatiles in liquid nitrogen cooled traps. The remaining gas is then pumped into an evacuated brass-walled proportional counter which is finally filled to 1 atmosphere pressure with argon-methane counting gas.

The A^{41} (109 min. half-life) and A^{37} (35-day half-life) activites are used to evaluate the total amount of A^{40} in the sample and the atmospheric contamination.

For the irradiation conditions used 10^{-6} c.c. (STP) of atmospheric argon produces 6×10^3 cpm of A^{41} activity and an A^{41} to A^{37} count ratio for air argon of approximately 400 (at the time of removal of the sample from the reactor). Longer irradiation will reduce this ratio to less than 100.

The good reproducibility obtained on multiple runs on standards permits the present method to be used for dating old rocks with ease and younger rocks (late Cenozoic) with a little further refinement. Several rocks from Greenland are being dated by this method, and a preliminary age of 1.6 b.y. is reported for the biotite of a granodioritic gneiss from the head of Sondre Strømfjord, West Greenland.

POTASSIUM-ARGON AGE OF BIOTITES FROM CORDILLERAN GRANITES OF CENTRAL BRITISH COLUMBIA

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Biotites from 20 plutons of the Cordillera of North America, principally from British Columbia, have been dated using the potassium-argon method. Samples were selected from well-known intrusives in an attempt to compare physically measured dates with relative age established by geological mapping; most dates confirm geological age interpretation.

The Cordillera underwent five distinct periods of granitic intrusion or orogeny, separated by long periods of quiescence. The earliest, a Paleozoic orogeny of Taconic, Caledonian, or Acadian age, occurred 350 million years ago and resulted in intrusion of plutons as widely separated as the Ice River syenite of the Rocky Mountains and the Fitton granite of the northern Yukon.

Early Mesozoic orogeny emplaced the upper Triassic or lower Jurassic Guichon batholith (185 m.y.) and the Topley batholith (165 m.y.) of central British Columbia. The major Cordilleran intrusion occurred 95–100 million years ago, about the middle of the Cretaceous period, with emplacement of the Coast Range batholith and early phases of the Nelson batholith of British Columbia, and Cassiar and Itsi batholiths of Yukon. In late Cretaceous time, 80 million years ago, Bayonne, British Columbia, and Boulder and Marysville, Montana, were emplaced.

During Rocky Mountain orogeny (Eocene), 50–60 million years ago, late phases of Nelson and a number of smaller plutons such as Coryell were emplaced. Eighteen million years ago small granitic bodies were intruded into the Cascade Range (Miocene); these are believed to be the youngest exposed batholithic rocks in North America.

SIGNIFICANCE OF ADSORPTION ISOTHERMS FOR SPECIFIC ORGANIC MATERIALS ON SEDIMENTARY MINERALS

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The results presented in this paper represent one portion of an overall program to characterize these organic compounds and investigate their capacity for chelation in the sea and their mobility under varying conditions expected in the marine environment. Differential adsorption of specific organic compounds by various minerals is demonstrated. Amino acids, carbohydrates, fatty acids, and other organic materials known to exist in natural waters and deposits show a specific adsorption coefficient for specific minerals such as montmorillonite, kaolinite, illite, calcium carbonate, and quartz. Of the minerals and organic compounds investigated, amino acids and montmorillonite appear to have the greatest mutual affinity. Data on the effect of water salinity and temperature ranging from 0 to 36‰ and 5° to 25° C. are also presented in the development of adsorption isotherms for selected organic compounds and minerals. The method of investigation consists basically of using C-14 and H-3 labeled organic compounds. As developed, this method is rapid and permits a far greater sensitivity for following the process in both low and high concentrations than possible with other analytical or chemical methods.

APPLICATION OF THE CONCEPT OF FACIES TO CHEMICAL ASPECTS OF GROUND WATER

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The notion of facies provides the conceptual model for explaining the distribution and genesis of the principal chemical types of ground water in the Cretaceous and Tertiary formations in the

northern portion of the Atlantic Coastal Plain. Significant parameters of these hydrochemical facies can be illustrated by methods similar to those used in lithofacies studies—trilinear diagrams, isometric panel diagrams, and maps showing lines of equal concentrations of individual constituents or concentration ratios of various constituents.

The development of hydrochemical facies can be thought of as a chemical response to the interrelated effects of the lithology and flow pattern of the hydrologic system. Within the Coastal Plain sediments the calcium-magnesium-bicarbonate facies occurs in areas of high head; the sodium-bicarbonate facies occurs in downgradient areas of lower head. Laboratory data on ion-exchange capacities indicate that glauconite, kaolinite, and montmorillonite are the controlling materials that bring about these changes. The distribution of the sodium-chloride facies in the Cretaceous sediments may be controlled by piezometric highs underlying higher landmasses in Maryland and New Jersey. Mapping of these facies demonstrates that the outcrop area of the Cretaceous and Eocene sediments in southern Maryland and southern New Jersey functions as a discharge area for ground water, rather than a recharge area as is more normally the role of the outcrop of artesian aquifers.

CONTACT FUSION OF ARGILLACEOUS AND ARKOSIC SEDIMENTS BY AN ANDESITE INTRUSION, VALLES MOUNTAINS, NEW MEXICO

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A small (150 by 600 feet) discordant andesite intrusion 9.6 miles west-northwest of Espanola, New Mexico, has partly fused arkosic sands and interbedded clays of Pliocene(?) age of the Santa Fe group up to 75 feet from the contacts.

Partly fused arkosic sands consist of relict detrital grains of quartz and feldspar imbedded in colorless glass (n = 1.486) containing abundant tridymite microlites. Detrital orthoclase and microcline are sanidinized and partly melted. Plagioclase grains have partly melted rims. Clay lenses consisting largely of illite are converted to glass containing microlites of cordierite, mullite, tridymite, hematite, and rutile. Near intrusive contacts fused sands and clays are mutually intermixed, flow banded, and contaminated by the andesite. Fusion glass (n = 1.490) contains orthopyroxene as well as cordierite microlites and merges with diffuse andesitic veinlets of brown glass (n = 1.496) containing clinopyroxene and magnetite crystals.

The andesite contains microphenocrysts of bronzite ($En_{78}Fs_{22}$) with pigeonite ($Wo_9En_{68}Fs_{23}$) overgrowths, augite ($Wo_{42}En_{43}Fs_{15}$), and laboradorite ($An_{50\text{-}58}$). Highly siliceous interstitial glass (n = 1.496), high-bulk (62%) silica content, and abundant partly dissolved xenoliths indicate considerable assimilation of the country rock.

Compositions of coexistent bronzite and pigeonite suggest the andesite was molten above 1100° C. Artificial fusion of samples of the arkosic sand indicates that the temperature of the fused sediments was at least 1000° C.

TRIASSIC REPTILES FROM NOVA SCOTIA

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The Wolfville sandstone, basal formation of the Newark group in Nova Scotia, bears isolated reptile bones at several shore outcrops around Minas Basin. Bone occurs chiefly in poorly sorted,

reddish-brown arkose, less commonly in micaceous sandstone and siltstone. The fauna, still incompletely sampled and studied, includes pseudosuchians and procolophonid cotylosaurs.

A new genus of spiny procolophonid shows affinities with *Hypsognathus* from the lower Brunswick formation of New Jersey and Pennsylvania. Its posterior cheek teeth are sectorial rather than molariform, however, and bear serrated chisel-like crowns aligned antero-posteriorly. This novel specialization is further developed in *Colognathus* [*Xenognathus*] from the Dockum group of Texas, a hitherto problematical genus now clearly assignable to the Procolophonidae.

Pseudosuchian remains include caudal scutes and a vertebra of *Stegomus arcuatus*, an aëtosaurid known from the New Haven arkose of Connecticut and the lower Brunswick formation of New Jersey; an ilium closely resembling that of *Stagonolepis;* and unidentified vertebrae, scutes, and a basicranium. Fragments represent other reptilian groups.

Episodic volcanism, lithologic similarities, and the reptilian faunas suggest the following correlation of the Acadian Triassic with other sequences of the Newark group:

Nova Scotia	*Connecticut Valley*	*New Jersey*
	Portland arkose	Boonton and Whitehall beds
	Hampden basalt	Hook Mountain basalt
Scots Bay fm.	Meriden posterior shale	Brunswick fm. (partim)
North Mountain basalt	Holyoke basalt	Second Watchung basalt
Blomidon shale	Meriden anterior shale	Brunswick fm. (partim)
unnamed basalt	Talcott basalt	First Watchung basalt
Wolfville sandstone	New Haven arkose	Lower Brunswick fm.
		Lockatong fm.
		Stockton fm.

LANDSLIDE PROBLEMS IN THE APPALACHIAN PLATEAU

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This paper describes the relative severity of the landslide problem in the Appalachian Plateau and particularly within the Kanawah section as defined physiographically by Fenneman. Severity is discussed in terms of number of occurrences, type of landslides, and the size of moving mass. More than 700 landslides were utilized as a basis for the study, and more than 500 were taken from the experiences of the writer in West Virginia. Rock falls, earth slumps, earth flows, and combinations thereof constitute 80–90 per cent of the mass movements reported. A significant majority of the landslides are small, involving less than 50,000 cubic yards of material.

The analysis is framed within a regional concept, for the purpose of defining the landslide problem. Geomorphology is designated as contributing the most significant characteristic. Strong secondary factors are strength of the materials and structure. Soils will more consistently lead to slope failures than will bedrock or well-consolidated masses. Structure becomes critical in terms of weak planes and of differential permeability. Excluding rock falls and dry runs, differential permeability within the bedrock mass, and again at the rock-soil interface, provides the excess water associated with many mass movements.

Implications of the use of a regional approach in the prevention, correction, and legal problems are related to the extrapolation of experience to new areas and to the ability to relate geologic descriptions to engineering solutions.

SYSTEM ZnS-H_2S-H_2O

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Phase equilibria and the solubilities of ZnS and H_2S have been determined from 25° to 180° C. and 100 to 600 p.s.i. in this system. The only solid phases existing under these conditions are ZnS and $H_2S \cdot 6H_2O$.

In the H_2S-saturated aqueous phase, ZnS readily forms a suspension which gives rise to an experimental background of 1. mg/L (~1 ppm). The solubility of ZnS in the aqueous phase does not exceed the background concentration up to 180° C. and 600 p.s.i. The calculated pH, based on the measured solubility of H_2S in the aqueous phase, ranges between approximately 2 and 4 over this P-T range. Lack of appreciable solubility in this aqueous phase under large partial pressures of H_2S suggests that an aqueous phase may be incapable of transporting ores.

The solubility of ZnS in liquid H_2S (in equilibrium with gas) is less than 0.1 mg/L at both 25° C., 300 p.s.i., and 50° C., 520 p.s.i.; however, in H_2O-saturated liquid H_2S, the solubility at 50° C., 510 p.s.i., is 11 ± 2 mg/L. This sulfide liquid is immiscible with H_2O, but it is too reduced to deposit common ores. The addition of sulfur to this liquid increases its stability and oxidation state and forms polysulfide liquids; these must be investigated as potential ore transporting media.

ELECTRUM-TARNISH METHOD FOR DETERMINING THE CHEMICAL POTENTIAL OF SULFUR IN LABORATORY SULFIDE SYSTEMS

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Knowledge of the chemical potential of sulfur (here calculated for the species S_2) of sulfide assemblages is important in the interpretation of natural sulfide assemblages, as an aid in phase-equilibrium studies of sulfides, and for the determination of fundamental thermodynamic properties of sulfides. Values of μ_{Ag} (chemical potential per formula weight) in gold-silver alloys and of the free energy of formation of argentite, taken from the literature, permit the calculation of μ_{S_2} as a function of temperature for the univariant reaction

$$2Ag \text{ (dissolved in electrum)} + \tfrac{1}{2}S_2(g) = Ag_2S \text{ (argentite)}$$

under the stipulation that too little argentite is formed to change the composition of the electrum significantly. Gold-silver alloys of various compositions are sealed in evacuated silica-glass tubes with the sulfides to be studied and adjusted to a temperature at which an argentite tarnish just appears on the alloy. The chemical potential of S_2 in the system is then calculated from the above reaction. No significant error appears to be introduced by the assumption that the argentite is pure Ag_2S.

Application of the method to the assemblage pyrite-pyrrhotite has yielded results in agreement with those obtained by other methods and reported in the literature. Preliminary experiments on the assemblage covellite-digenite suggest that presently accepted values for this pair may require revision. Experiments are under way to measure μ_{S_2} of pyrrhotite as a function of the Fe:S ratio and temperature, and of pyrite-sphalerite pairs as a function of temperature and Fe:Zn ratio in the sphalerite.

MACERAL SEGREGATION IN COMMERCIALLY PREPARED COAL PRODUCTS

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Samples of 13 individual coal products were collected at a cleaning plant for the purpose of investigating the effects which each cleaning or sizing device had upon the maceral and mineral composition of the resultant coal fractions.

The preparation plant investigated included Chance cones, Deister tables, and vacuum filters in the cleaning circuits.

Each product was examined petrographically to determine the relative abundance (per cent) of the following entities: Vitrinoid type II, Vitrinoid type IV, Vitrinoid type V, Exinoid type 1, Fusinoid type 1, Fusinoid type 2, Micrinoid type 1, Mineral Matter.

Examinations of these products showed that: (1) the cleaning and sizing units in the preparation plant yielded products which differed in composition from the maceral and mineral content characterizing the raw coal; (2) large quantities of usable coal entities are being discarded in the primary Chance cone refuse; (3) further crushing of the raw coal would result in greater reclamation of coal entities; and (4) although the cleaning plant was not designed to control the maceral composition of the coal products, it has effectively prepared products enriched in specific maceral types.

MORPHOLOGICAL VARIATIONS IN THE TERMINAL GROWTH STAGES OF MODERN PLANKTONIC FORAMINIFERA

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Ontogenetic studies of various modern species of planktonic Foraminifera indicate that there are several ways in which individuals modify their shells when "maturity" is reached. One or more of the following morphological changes may appear in the late stages of individual species: (1) increase in shell thickness, either in selected parts of the test (*Globorotalia menardii*, *Globigerina pachyderma*) or over the entire surface of the test (*Sphaeroidinella dehiscens* and most planktonic Foraminifera); (2) addition of a diminutive final chamber (*Globorotalia truncatulinoides*, *Globigerina pachyderma*, etc.); (3) addition of a radically different final chamber (*Globigerinoides sacculifera*, *Orbulina universa*); (4) division of the primary aperture into two or more secondary apertures (*Globigerinoides conglobata*, *Globigerinita glutinata*); and (5) change in plane of coiling (*Pulleniatina obliquiloculata*).

Thin-shelled individuals are proportionately more abundant in near-surface waters, although not necessarily smaller, than those in the deeper waters (below 200 m) or in the dead assemblages on the ocean floor. The morphological variations mentioned are seldom seen in individuals living within the euphotic zone, but they are frequent in deeper plankton tows and in the empty tests on the ocean bottom. The conclusion is reached that, although planktonic Foraminifera carry out the bulk of their developmental stages in the euphotic zone, considerable shell modification may continue in the aphotic zone (below 200 m).

GRAPTOLITE FAUNAS OF THE DEEPKILL SHALE

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The graptolite zonal sequence in the Deepkill shale worked out by Ruedemann nearly 60 years ago and the faunas that constitute the zones have been considered the standard of comparison for all Early Ordovician graptolites in North America. Also, the term "Deepkill" has acquired time-stratigraphic significance in some publications. Reinvestigation and reinterpretation of the formation

and its faunas reveal that four zones based on graptolite assemblages may be delimited within it. Three of the zones are in the continuous exposure (Ruedemann's beds 1 through 5) in the lower part of the Deepkill gorge. The two older zones are latest Early Ordovician, and the third zone is earliest Middle Ordovician. The rocks of the fourth zone, which comprise Ruedemann's beds 6 and 7, are in fault contact with the Normanskill shale. This zone is mid Middle Ordovician. One zone is missing between it and the next youngest zone in the Deepkill shale. The missing zone, although widely represented in other parts of the country, has not been found anywhere in New York.

The graptolites in the Deepkill shale are much more Australian in affinity than has previously been acknowledged, and several Scandinavian forms are present as well. Thus, representatives of two faunal regions are in the formation.

PATTERN OF REGIONAL TRANSCURRENT FAULTING IN PUERTO RICO

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Puerto Rico is an intensely faulted anticlinorium across which the lineation of the major faults is west-northwest. The indicated age of the main period of faulting is either early or middle Eocene.

Two principal faults or sets of faults divide the island into three blocks—northeastern, central, and southwestern—each of which contains a set of subordinate faults having a characteristic lineation. The northeastern block contains faults that strike northwest. The central block has a more complex structure but contains an interwoven network of northwestward- and northeastward-striking faults. The southwestern block is cut by faults that generally strike east-west.

The orientation of the subordinate faults to the two main faults suggests tear faulting formed by regional transcurrent movements. The indicated relative directions of movement are toward the southeast for the northeastern and southwestern blocks and toward the northwest for the central block. The mechanics, however, included rotation of the several fault blocks so that both vertical and high-angle reverse movements occurred with the transcurrent movements.

Transcurrent faulting within the Greater Antilles is of regional significance because the lineation of the Puerto Rico faults in general parallels a belt of east-west-trending transcurrent faults in northern Venezuela. The positions of the two parallel belts of transcurrent faulting support the theory that the Caribbean region is a crustal block that is moving eastward.

TRACE-ELEMENT DISTRIBUTION AS AN INDICATOR OF PRESSURE AND TEMPERATURE OF ORE DEPOSITION

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The partitioning of an element between coexisting minerals can be described by a distribution constant, K, which is a function of both temperature and pressure, but is independent of the bulk concentration of the element in the compositional range considered. For elements present in minor amounts the distribution constant reduces to the form:

$$K_D = \frac{\text{atomic percent element in mineral A}}{\text{atomic percent element in mineral B}}$$

In the general case, such constants determined for two minor elements distributed between two minerals formed in equilibrium may be used to define uniquely the pressure and temperature of formation. Evidence for equilibrium is provided if concordant pressure-temperature values are obtained for three or more minor elements.

Experimental work yields the following equations for the distribution of selenium and of cadmium

between sphalerite and galena, and of selenium between chalcopyrite (experimentally, $CuFeS_{1.8}$) and galena, in the temperature ranges given:

Distribution constant K_0 (mole %)	Temperature range of experiments (°K)	Equation determined
$\frac{\text{PbSe in galena}}{\text{ZnSe in sphalerite}}$	872–1163	$\log K_0 = \frac{\frac{1}{T°_K} - 0.00044}{0.00035}$
$\frac{\text{1.9 (PbSe in galena)}}{\text{CuFeSe}_{1.9}\text{ in chalcopyrite}}$	748–868	$\log K_0 = \frac{\frac{1}{T°_K} - 0.00080}{0.00031}$
$\frac{\text{CdS in sphalerite}}{\text{CdS in galena}}$	872–1163	$\log K_0 = \frac{\frac{1}{T°_K} - 0.00072}{0.00066}$

Pressure effects in the above systems are small. Manganese is strongly concentrated in sphalerite relative to galena but less so with increasing temperature and pressure.

Primary growth zoning and secondary re-equilibration are possible sources of error for geological application of the method.

MINERALOGY AND PETROLOGY OF A RODINGITE DIKE, HINDUBAGH, PAKISTAN

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A rodingite dike is described from Pastoki, 15 miles south of Hindubagh, Pakistan, and chemical analyses are given of the serpentine country rock represented by a xenolith in the dike, of four specimens of rodingite, and of typical unaltered dolerite dike of the area. The mineralogy of the rodingite includes the extensive development of calcium-rich minerals such as prehnite and hydrogrossular, and the dike is traversed by numerous veins of xonotlite. Analyses and optical properties are given for hornblende, prehnite, sphene, chlorite (pycnochlorite), diopside, and xonotlite from the rodingite and for lizardite from the serpentine xenolith. The chemistry and mineralogy of the rodingite indicate the introduction of calcium, carbon dioxide, and water and the removal of sodium and potassium. The calcium-rich hydrothermal solutions involved may be related to the serpentinization of the peridotite country rocks.

PLEISTOCENE MAN IN SOUTH-CENTRAL WISCONSIN

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Archeologic excavations and geologic study of Raddatz Rockshelter, Sk 5, beneath the natural bridge in Sauk County, Wisconsin, establish man's presence at the close of the Valders substage and suggest his presence along the front of Cary ice. Wittry excavated an Archaic culture identified by hundrends of artifacts of chipped and ground chert, basalt, bone, teeth, and shell. Several hundred pounds of split deer bones and other faunal remains, hundreds of firebeds, and several artificial pits attest to man's presence.

The rockshelter was carved by a combination of weathering and erosional processes from upper Cambrian sandstone. Only part of the shelter deposits accumulated from the walls and ceiling. Three loess zones in the lower part of the deposits are correlated respectively with the Valders, late Cary, and pre-late Cary substages of the Wisconsin. Artifacts first appeared immediately after the youngest loess; involutions are common to older strata, and permafrost conditions are assumed through Valders time. Charcoal in possible firebeds and in disseminated grains and layers occurs between the two oldest loesses.

The chronology later was confirmed with a carbon-14 date of 11,611 ∓ 600 years B. P. (sample M-812) on charcoal from a possible firebed (depth of 7.5 feet) previously correlated with the Two Creeks interval and between the youngest two loesses. A date of 5,200 ∓ 400 years B. P. (sample M-813) on charcoal from a depth of 3 feet (4 to 5 feet below the reconstructed surface) substantiates the linear extrapolation to main archeologic horizons.

LATE PLEISTOCENE EVENTS IN SOUTHWESTERN MAINE*

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Marine sediment containing a cold-water fauna unconformably overlies glacial drift on the coastal plain of Maine east of the Saco River and is known from well logs to overlie drift at depths of at least 60 feet below present sea level. An interval of subaerial exposure of the deglaciated landscape prior to submergence is indicated. The area of postglacial marine submergence coincides with an area of glacial lineations that indicate southward flow of glacier ice.

West of the Saco River, glacial lineations show that the final movement of glacier ice was toward the southeast, from the direction of the White Mountains. In parts of the area west of the Saco River southeast-flowing ice entered the sea and deformed previously deposited marine sediment at a time when sea level was at least 40 feet above its present position relative to the land. Thus the southeastward glacial movement west of the Saco River was later than the southward movement east of the river.

Marine submergence may have been in progress 11,800 years B. P., based on one radiocarbon age determination on marine shells from Waterville, Maine. A line of marine deltas and delta fans built by meltwater streams marks the inland limit of marine submergence and shows that deglaciation of southwestern Maine occurred less than 11,800 years B. P. Pollen stratigraphy implies that reemergence of the coastal plain was in progress 7000–8000 years B. P. Emergence was accompanied by differential upwarping toward the northwest, presumably the result of postglacial isostatic recovery of the Earth's crust.

SIGNIFICANCE OF OSCILLATORY ZONING IN ALKALI AND PLAGIOCLASE FELDSPARS IN GRANODIORITE FROM NORTHERN MAINE

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Oscillatory zoning, strongly developed in plagioclase and less fully in orthoclase microperthite, probably reflects abrupt changes in $P_{volatiles}$ during crystallization in a magmatic system, open as regards its volatile components. Both zoning and complex mantling are interpreted as products of nonequilibrium crystallization.

Changes of An content (An_{24}-An_{36}) across zones in plagioclase and of Or content (Or_{68}-Or_{72}) across zones in microperthite conform to trends of compositional change expected in two-feldspar melts crystallized at different pressures of H_2O (Yoder, Stewart, and Smith, 1957).

* Based on studies carried out under office of Naval Research Project No. NR 388–040

The change of $2V_x$ within zones of microperthite crystals records a gradational change from more sodic to more potassic orthoclase from the inner to outer margins of each zone; the abrupt change from potassic to sodic compositions, marking the zone boundaries, suggests interruptions in the gradual increase of $P_{volatiles}$. Similarly, the change from sodic to calcic compositions from one zone to another in plagioclase is sharply defined and commonly marked by an absorption interface. Successive release of volatiles from the magma is appealed to as a mechanism for causing the interruptions in the normal increase of partial pressure. The rate of crystallization was greater than the rate of continuous reaction between crystals and liquid.

It is concluded that, during crystallization attended by increasing $P_{volatiles}$, alkali feldspar of higher Or content precipitated contemporaneously with coexisting plagioclase of higher Ab content, whereas at lower, or with decreasing, $P_{volatiles}$, zones of lower Or content formed on alkali feldspar crystals, as zones of lower Ab content formed on plagioclase.

MIDDLE OR UPPER ORDOVICIAN IN NOVA SCOTIA

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Middle or Upper Ordovician fossils—the first in the eastern part of the Northern Appalachians (Nova Scotia, coastal New England and New Brunswick)—have been found on Cape George, Antigonish County, Nova Scotia. The fossils are in an undescribed quartzite that occurs as blocks up to 200 feet long in a late Paleozoic fault zone on the east side of Cape George and as boulders in Carboniferous conglomerate associated with the same fault. The fossils include *Rafinesquina* sp., *Rhynchotrema* sp., *Kaierina?* sp., an unidentified atrypacean, *Tentaculites* sp., and an unidentified trilobite. The Ordovician quartzite is unlike any rocks observed in the nearby pre-Silurian Browns Mountain group. The quartzite blocks in the fault zone are associated with blocks of another quartzite containing *Scolithus*-like tubules and unidentifiable fish fragments (Ørvig, 1959, written communication).

The fault zone also contains Silurian blocks belonging to the Arisaig series. These include blocks of Ross Brook formation lithology from which Ami (1895) has described invertebrates, blocks from the Moydart formation (from both the "red band" and underlying portions), and fish-bearing blocks of probable Stonehouse from which Ørvig (1959, written communication) reports: "seems to consist of Thelodontid scales (of the *Thelodus parvidens* kind), and Acanthodian spines and scales, the latter being referable to *Nostolepis* sp. and "*Gomphodus*" sp. The fauna, then, seems to be an Upper Silurian (Upper Ludlovian) one."

GEOLOGY OF THE RED MOUNTAIN GNEISS, LLANO COUNTY, TEXAS

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The Red Mountain gneiss occurs as several northwest-trending sill-like masses of granite gneiss near the top of a thick sequence of Precambrian metasedimentary rocks (Packsaddle schist). Magmatic origin of the Red Mountain gneiss is evidenced by xenoliths and schlieren of schist in the gneiss, relict porphyritic texture in thin sills of granite gneiss, and locally discordant contacts of gneiss with schist. The granite gneiss grades from slightly foliated to strongly deformed granite, being finer-grained and more schistose toward the north. Big Branch quartz diorite gneiss borders the schist and granite gneiss to the south. Near the granite gneiss, the quartz diorite has been coarsened and enriched in potassium feldspar to produce a quartz monzonite augen gneiss.

Foliation within the granite gneiss parallels sill contacts and relict bedding of the metasedimentary rocks. Lineation in all the rocks parallels major fold axes and plunges southward. A north-trending Precambrian shear zone which approximately bisects the Red Mountain area is characterized by extreme fracturing of the rocks and marked rotation of lineation and foliation. Several northeast-

trending Paleozoic faults also are present, and tilting adjacent to these high-angle normal faults has generally deflected the foliation by rotation about axes almost parallel to lineation.

An east-west set of tensional joints filled with vein quartz is prominent, and at least two other sets of mineralized Precambrian joints are present. Nonmineralized joint sets which strike northeast and northwest probably represent conjugate shear joints developed by late Precambrian deformation.

USE OF MOHR CIRCLES IN THE ANALYSIS OF LARGE GEOLOGIC STRAIN

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The definition of finite homogeneous strain and the significance of strain analysis is reviewed. Contrary to widespread geologic opinion, use of finite homogeneous strain theory and properties of the strain ellipsoid does not require that material be isotropic or that Hooke's law holds. The immediate purpose of strain analysis is determination of the magnitude and orientation of principal strain axes.

Large strain is analyzed most simply by a semigraphical method originated by Nadai based on Mohr circles. The method is sketched here for a simple two-dimensional problem. The types of observations in geology which yield principal strains and under certain conditions even volume change include deformed bivalves and a wide variety of distorted primary sedimentary structures in addition to the familiar stretched pebbles, oöids, and crinoid sections.

DRAINAGE FROM COAL MINES

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The acid discharge water from coal mines results from the atmospheric oxidation of sulfuritic iron compounds in the coal seam and the associated strata. The sulfuritic iron compounds in the form of pyrite or marcasite react with oxygen to produce ferrous sulfate and either sulfur dioxide or sulfuric acid depending upon the moisture present during the reaction period. There is a vast difference in the oxidation rate of different crystal forms of the sulfuritic materials. Although the reaction type is the same, the composition of the water solution varies with the amount and type of geologic strata in which it is embedded or with which it is associated. These secondary reactions result in mine water discharges of many compositions and varying degrees of acidity and alkalinity.

GEOLOGIC ASPECTS OF ACID MINE WASTES IN OHIO

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Various geologic conditions prevail in the Appalachian coal basin to produce large quantities of dissolved solids and acids. The basis of the phenomenon and problem is the oxidation of pyritic materials, either pyrite or marcasite, in various modes of occurrence. The acid and salts (sulfates of iron) produced may react with clay minerals to produce complex aluminium-iron sulfates. Water is carried into rock strata by various routes in which equilibrium is disturbed by mining processes. Water entering mines becomes the transporting agent of the salts formed in the mines. The acids may come from the coal or from the overlying shales; from gob from the coal-mining or cleaning-plant process; or from sulfuritic materials in spoil banks of strip mines. Basic to alleviation of the acid production is a method of separating one of the reactants—oxygen, pyritic material, or moisture.

EXTRACTABILITY OF HUMIC SUBSTANCES FROM COALIFIED LOGS AS A GUIDE TO TEMPERATURES IN COLORADO PLATEAU SEDIMENTS

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Tree trunks and woody fragments buried in uranium-bearing Triassic and Jurassic sediments of the Colorado Plateau have been converted into lignite, subbituminous coal, or high-volatile bituminous coal. There is abundant evidence that alkaline ground water prevailed in the region; this water would be expected to extract soluble humic substances from the coal. Inasmuch as such extraction is dependent upon temperature, studies were carried out to determine the maximum temperatures at which such extraction may have occurred.

Nine coal samples, eight of which were high-volatile A bituminous in rank, were each extracted with 0.1*N* sodium hydroxide at 100°C. The quantity of extractable organic matter in the coal was determined chemically, and the insoluble residue was washed and re-extracted at 110°C. This procedure was repeated at 120°, 130°, 140°, and 150°C.

Analysis of the extractability curves indicates that none of the samples had been exposed to temperatures over 120°C. in the presence of alkaline solutions; five of the samples had never been at temperatures over 100°C. under the same conditions. This completely different approach to geothermometry indicates a temperature concordant with that to be expected from geothermal gradient (80°–120°C.) and that indicated by mineralogic evidence (less than 140°C.).

PERMO-PENNSYLVANIAN STRATIGRAPHY IN SOUTHEASTERN NEVADA, WESTERN UTAH, AND NORTHWESTERN ARIZONA

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Distribution and thickness of Permo-Pennsylvanian strata are influenced by two basins in southeastern Nevada and the Oquirrh Basin of Utah. At times sediments lapped over the adjacent shelf areas. Directional properties and lithofacies suggest that sediments were derived mainly from a central Utah highland and from the Manhattan geanticline.

Springerian strata are confined to the basins and are present in the northern part of the area. Morrowan and Atokan strata are widespread in both basin and shelf areas. DesMoinesian and Missourian strata are confined to the basins. Virgilian strata are confined to basins except in northwestern Arizona where they interfinger with the lower Supai. Lower and upper Wolfcampian strata are confined chiefly to basins. Middle Wolfcampian strata are widespread in both basins and adjacent shelves. Leonardian strata of eastern Nevada seem to correlate with the "Supai" of Utah, the Diamond Creek sandstone, and the upper Supai and Hermit shale of Arizona. The heavy minerals suggest a western source for the clastic sediments of the Leonardian of Nevada and an eastern source for the Diamond Creek sandstone and equivalents. Guadalupian strata consist of the Toroweap formation in the southern part of the area, the Kaibab formation and equivalents which are widespread, and the Phosphoria equivalents in the northern part of the area.

Correlation is based on fusuline and macrofossil zones and on lithology.

INTERPRETATION OF AEROMAGNETIC DATA ACROSS THE READING PRONG, PENNSYLVANIA

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Results of a detailed aeromagnetic survey in southeastern Pennsylvania by the U. S. Geological Survey in co-operation with the State of Pennsylvania show that the Precambrian rocks of the

Reading Prong produce a characteristic "birds-eye-maple" magnetic pattern from which the areal extent of their surface and near-surface occurrences may be determined.

A profile across the Reading Prong was constructed from the aeromagnetic data along a 14-mile line from Pleasant Valley, northwestward across Saucon Valley, through Bethlehem, to Jacksonville. A broad positive magnetic anomaly in an area of Cambrian and Ordovician sedimentary rocks 3 miles north of Bethlehem is interpreted as caused by Precambrian rock buried at a depth of 1 mile. The exposure of Precambrain rocks at Pine Top and Camels Hump on the south side of the anomaly has little magnetic expression, but Precambrian rocks exposed 5 miles to the northeast have a pronounced magnetic expression. Interpretation of the magnetic profile indicates that Saucon Valley is a down-faulted block, and that the top of the Precambrian in the valley is 4000 feet below the surface. It also indicates that the Precambrian–Triassic contact on the Reading Prong is a nearly vertical fault with the south side downthrown 3000 feet. The Precambrain surface beneath the Triassic rocks slopes to the southeast.

CHEMICAL ASPECTS OF THE FORMATION OF PETROLEUMS AND NATURAL GAS

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The most significant fact regarding petroleums and natural gas is their complexity and diversity of composition. This fact, frequently overlooked, makes their formation a chemical problem.

The history of petroleums may be divided into (1) the period of deposition, and (2) the period of transition to typical petroleums. Few facts are known regarding (1), but there is evidence that geologically young oils change in composition, with progressive gas formation, during geologic time. Little change results after the crude contains 35–40 per cent gasoline, or in oils older than Late Cretaceous.

Explanation of these changes lies in chemical reactions investigated along three lines: (1) long known reactions effected by fullers earth (montmorillonite), (2) reactions studied since 1931, including polymerization, alkylation, and isomerization, effected by acid catalysts, (3) reactions occurring in catalytic cracking, studied since 1949, effected by catalysts having acid properties. These reactions are believed to take place through carbonium ion reactions and explain the complex composition of petroleums. Thus alkylate contains substantially the same hydrocarbons as the corresponding fractions of straight-run gasolines.

Many sedimentary rocks contain layer-lattice silicates such as montmorillonite or illite. Changes in composition of petroleums are probably arrested after migration into noncatalytic reservoir rock. There is no necessity for hydrogenation in the formation of crudes containing gasoline and wax.

Some anomalies and unsolved questions will be pointed out. Obsolete theories will not be discussed.

DISCUSSION OF LEAD-ISOTOPE DATA FOR SOUTHEAST MISSOURI

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In a large measure the authors concur with Kulp and Eckelmann as to the pattern of isotope variation developed by this investigation and its significance as to the source region and direction of travel of ore solutions. These clearly seem to have risen through the basement and dispersed upward and outward as they were deposited in the sedimentary cover.

There is genuine disagreement, however, as to the time relations of more and less radiogenic lead. Several well-distributed and clearly geologically dated samples show that the more radiogenic lead was definitely deposited last. In the authors' opinion this necessitates some fundamental revision of the proposed mechanism of source, derivation, and deposition processes.

ABSENCE OF CROSS-STRATIFICATION IN THE BED REGIMES OF DENSITY UNDERFLOWS

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The absence of cross-stratification in deposits attributed to density underflows (turbidities) can be explained by considering some elementary principles of fluid mechanics and by examining the criteria which determine bed regimes in open channels. Ripples, dunes, and bars cause cross-stratification to form in the bed of an open channel whereas antidunes form only slightly undulating structures. Antidunes form at supercritical (shooting) flow and occur where the Froude number exceeds one. The dimensionless Froude number has identical significance for density underflows but varies with the density contrast between the fluids.

On bed slopes of 2°–5°, typical of submarine canyons and continental slopes, most density underflows will move at supercritical velocities. At these bed slopes, any particle movement will cause the antidune regime to form thus omitting the ripple, dune, and transition regimes which form cross-stratification. The same effect occurs in open channels where particle size exceeds about 20 mm or where the particles have large specific weights. In density underflows, the effect is caused by the small density differences between the fluids.

Quartz particles 2.0 mm or larger will move on slopes of 2°–5° for a wide range of contrast in fluid density. Thus for the typical conditions of practical interest, the flow is competent as well as supercritical and results in the development of nearly horizontal strata devoid of cross-stratification.

RAPID METHOD FOR MEASURING HEAT FLOW AT SEA

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Present methods of measuring heat flow at sea are extremely tedious. They involve the lowering of a temperature probe to the sea floor, leaving it there for between half an hour and an hour, and recovering it. This operation takes about 3 hours and is followed by the taking of a core which occupies about another 3 hours. Both parts of the operation are liable to occasional failure which is not detected until the equipment is raised.

It seems possible to design a nonrecoverable equipment which is thrown into the sea, sinks to the bottom, and measures both temperature gradient and conductivity. While the apparatus is sinking and getting into temperature equilibrium the ship could carry out other work. At a pre-set time the probe would send an acoustic signal giving its inclination to the vertical, its depth of penetration, and the temperature gradient. It would then release a known amount of heat in the probe and signal the rise of temperature after a fixed time. This would enable the conductivity to be found.

The equipment would need considerable effort to develop and would not be cheap, but the saving of several hours of ship's time should lead to substantial economies. Possibly the method could be used to measure the heat flow from the moon during an unmanned lunar landing if the maria prove to be covered with a large thickness of dust.

PRE-BELTIAN BASEMENT IN SOUTHERN ALBERTA AND ADJACENT BRITISH COLUMBIA

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Recent potassium-argon dating of biotites separated from samples of the basement complex in southern Alberta, southern Saskatchewan, and northern Montana indicate that this area was meta-

morphosed 1.7 to 1.9 billion years ago. Gravity studies in Alberta indicate a trend of N.50° E. for the major gneissic complexes.

Differential uplift of basement fault blocks during pre-Mesozoic epeirogenic movements is reflected in sedimentation and erosion trends of the Alberta shelf. The two dominant trends are N. 10° E. and N. 90° E. Observed faults of late Precambrian and Paleozoic age in southeastern British Columbia parallel the trends on the Alberta shelf. The Beltian sediments of the East Kootenay area were probably deposited on a stable continental shelf underlain by a gneissic complex of the same age and fabric as that of the Alberta shelf.

STRUCTURAL GEOLOGY OF THE CATHEDRAL PEAK AREA, BEARTOOTH MOUNTAINS, MONTANA

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The Cathedral Peak area includes 35 square miles within the Precambrian core of the Beartooth Mountains and is bounded by the Stillwater River on the east and Stillwater igneous complex on the northeast. The major rock type is a foliated biotite granitic gneiss. Minor elongated bodies of mica schist, banded hornblende gneiss, and other metasedimentary rocks are generally conformable to the foliation of the granitic gneiss. Foliation and compositional banding of the metasedimentary rocks, presumably representing original bedding, and foliation of the granitic gneiss show monoclinic symmetry. Both the megascopic fabric and the outcrop pattern indicate a series of open folds whose axes trend north-northwest and plunge to the north. Directions of mineral elongation and minor fold axes parallel the *b* axis. In the southern part of the area, the fold axes plunge 10°–15° N., but the plunge increases to 40° near the base of the Stillwater complex. This change in plunge may have been caused by rotation of fault blocks during Laramide uplift and thrusting, or by sagging of the floor of the lopolith represented by the Stillwater igneous complex. Postulated major events of geologic history are as follows: (1) Deposition of sedimentary sequence, (2) folding caused by approximately east-west compression, (3) regional metamorphism and granitization, (4) emplacement of the Stillwater lopolith, (5) slight tilting of the lopolith followed by peneplanation, (6) deposition of Paleozoic and Mesozoic sediments, (7) Laramide orogeny.

GEOTECTONIC RELATIONS IN NORTHERN VERMONT AND SOUTHERN QUEBEC

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The Appalachian orthogeosyncline in Vermont and nearby parts of Quebec contains Cambrian to Devonian bedded rocks that attest geosynclinal subsidence locally exceeding 50,000 feet. A broad eugeosynclinal zone spreads southeastward from the St. Lawrence River and eastward from the Green Mountains to the Atlantic Ocean. A narrow miogeosynclinal zone, which has a maximum width in the Champlain Valley, intervenes between the eugeosynclinal zone and the margin of the craton to the west. Thick stratigraphic units of the eugeosynclinal zone thin by convergence westward and merge gradationally with thinner units of the miogeosynclinal zone. The rocks are principally the graywacke-shale assemblage of the eugeosynclinal zone, derived chiefly from tectonic and volcanic islands in the eugeosynclinal zone. A subordinate carbonate-quartzite assemblage, characteristic of the miogeosynclinal zone, contains sediments derived mainly from the craton.

Consolidation of the orthogeosyncline with the craton began at the end of the Ordovician and is marked by eastward migration of the miogeosynclinal zone to a position a little east of the present Green and Sutton mountains of Vermont and Quebec respectively. Unconformities referred to the Taconic disturbance mark localized uplift. Angular unconformities in outlying regions to the south and east record general folding and uplift after the Early Devonian and are referred to the Acadian

and Appalachian orogenies; they mark completion of consolidation of the orthogeosyncline. Second- and third-generation geosynclines are superimposed upon the orthogeosyncline and adjoining parts of the craton. Critical magmatic features mark initial, synorogenic, subsequent, and final episodes of the diastrophic history.

BIOGEOCHEMICAL RELATIONS IN THE THOMPSON DISTRICT, GRAND COUNTY, UTAH

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The geochemistry of oxidized uranium deposits and the application of geochemical and geobotanical techniques to prospecting for uranium have been studied in the Thompson district on the Colorado Plateau. The uranium ores are in sandstone of Jurassic age and are strongly enriched in vanadium, arsenic, molybdenum, and selenium. There is a close association between uranium, vanadium, and selenium in the ores and very little separation of the elements during weathering.

The distribution of six species of plants was mapped, and subsequent drilling showed that *Astragalus pattersoni* and *A. preussi* consistently indicated a uranium-bearing sandstone at depth below the plants. Deep-rooted trees and shrubs of ubiquitous distribution were analyzed for uranium; their uranium content reflects the uranium content of the mineralized rock underneath.

Two thousand holes were drilled in the area to test geologic and botanical prospecting techniques. Eighty-one per cent of the drill holes that penetrated mineralized rock within a depth of 33 feet and 42 per cent of the drill holes that penetrated mineralized rock between depths of 33 and 170 feet were surrounded by indicator plants. Several ore bodies were found by botanical methods in areas that, on the basis of geologic criteria, were considered to be unfavorable.

SIGNIFICANCE OF LEAD ISOTOPES TO PROBLEMS OF ORE GENESIS

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Searching questions about the origins of ore deposits have been asked for many years. Where do ore fluids originate—within the crust, or deeper? Can specific sources of ore metals be identified? When were ores deposited? How long did mineralization continue? What was the rate and paragenesis of deposition? Which deposits are cogenetic, and what metallogenetic provinces do they define? Lead-isotope studies offer hope of obtaining some answers. Analyses of lead from rocks and ores, being made at about 20 laboratories, have begun to suggest partial answers and raise new questions.

Ore lead, as shown several decades ago, ranges widely in isotopic composition. Recent studies show that traces of lead in ordinary rocks of the earth's crust exhibit apparently similar variations. All these variations are attributable primarily to mixing of old lead with accumulations of new radiogenic lead from uranium decay and thorium decay. Each individual sample of lead preserves in its isotopic composition a record of its own mixing history. This constitutes a composite record of the time this lead was in different environments, its past associations with uranium and thorium, and the geochemical processes that moved it from place to place.

Integrated study of all these variables will throw light on many difficult problems of ore genesis when adequate techniques are developed. Progress will be slow, however, until more accurate lead-isotope analyses can be made at lower cost and more objective criteria developed for interpreting measured isotopic compositions in terms of geologic history.

GEOLOGY OF THE LINE CREEK AREA, BEARTOOTH MOUNTAINS, MONTANA-WYOMING

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An area of 15 square miles located near the 45th parallel includes a portion of the thrust front of the Beartooth Mountains which trends N.–S. to N. 20° E. The area has been studied from overturned Paleozoic sediments westward into Archean migmatites, granitic gneisses, and metasediments to determine the effects of Laramide deformation on Precambrian structures.

Detailed mapping (1:6000) of rock types, foliation, and lineation within the Archean has revealed an open symmetrical syncline plunging 25° at S. 50° W. Northwest and southeast of the syncline compositional banding has shown many smaller folds plunging parallel to the major structure. At the thrust front, however, the axes of these folds have the same plunge but in two different directions, S. 86° W. and S. 27° W. This is probably an effect of Laramide deformation.

In other parts of the range fracture-pattern studies by Spencer (1959) have shown that joints tend to lie in four vertical planes. In the Line Creek area the poles of the joint planes lie on three approximately perpendicular great circles—N. 30° E.–40° NW., N.–S.–50° E., and N. 85° W.–65° SW. The first two directions subparallel the thrust front and are a result of incomplete rotation of Precambrian joints into positions of optimum slip during Laramide thrusting. The third direction may be due to rotation about a vertical axis at the change in trend of the thrust front from N.–S. to N. 20° E.

It is concluded that fabric elements and fracture patterns reflect vertical uplift of the southeast portion of the Beartooth block. The fabric has been modified by gravity spreading due to uplift to a height such that the strength of the rock was exceeded.

ABUNDANCE OF ZIRCONIUM IN IGNEOUS ROCKS

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This study of the abundance of zirconium is based on spectrographic analyses, including many unpublished, of chemically analyzed rocks and shows some marked regional variations. Our results in general support the estimates of over-all abundance of Degenhardt (1957) rather than the earlier ones of Hevesy.

Basalts and andesites from island arcs of Japan, Palau, and the Aleutian Islands (averaging 10–60 ppm for basalts and 25–110 ppm for andesites respectively) contain less zirconium than those of the oceanic type of Hawaii and Polynesia (averaging 120–300 ppm and 250–520 ppm, basalts and mugearites respectively). For other volcanic rocks, zirconium increases generally in the order: dacites (50–250 ppm), latites (40–600 ppm), rhyolites (50–700 ppm), and trachytes (300–more than 1000 ppm). Within each geographic or petrographic province, the zirconium content generally increases with increasing total alkalies from basalt to dacite in the basalt-andesite-dacite-rhyolite sequence, or from basalt to trachyte in the basalt-andesite-trachyte-phonolite sequence; the increase of zirconium in the latter sequence is more rapid and noticeable than in the former.

For plutonic rocks, zirconium content is generally low in gabbros (less than 100 ppm), low to moderate in diorites and granodiorites (50–200 ppm), and low to moderately high in quartz monzonites and granites (50–700 ppm).

JOIN GROSSULARITE-PYROPE AT 1 ATMOSPHERE

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Members of the grossularite ($3CaO \cdot Al_2O_3 \cdot 3SiO_2$) and pyrope ($3MgO \cdot Al_2O_3 \cdot 3SiO_2$) series lie in the system $CaO \cdot MgO \cdot Al_2O_3 \cdot SiO_2$. Since neither grossularite nor pyrope is stable at 1 atm pressure above approximately 850°C. (the lowest temperature at which reaction rates are sufficiently rapid to allow crystallization from a glass), the join grossularite-pyrope is always quaternary. Because of the petrological significance of compositions along this join quenching runs have been conducted on glasses prepared at 10 weight per cent intervals to determine the subsolidus assemblages and temperatures of crystallization of the constituent minerals at 1 atm pressure.

Information on the temperatures of four invariant points has been obtained, and it has been shown that in the subsolidus region the important silica-rich portion of the system CaO-MgO-Al_2O_3-SiO_2 is divided into three significant volumes by the planes anorthite-melilite-pyroxene and anorthite-forsterite-spinel. By combining these data with those of previous workers the relationship of the quaternary invariant points and univariant lines in this portion of the system has been deduced.

These results serve as a basis for the more complex hydrothermal work now in progress at the Geophysical Laboratory.

CLEAVAGE AND FOLIATION IN THE MINERAL KING AREA, CALIFORNIA

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At Mineral King in the central, southern Sierra Nevada a vertically dipping metamorphic series includes Upper Triassic strata. Stratified rocks were isoclinally folded and intruded by synkinematic granodiorite and postkinematic granite. Deformation continued past the stage of isoclinal folding of bedding and produced two families of structural surfaces, referred to here as "cleavage" and "lithologic banding." Cleavage is a surface of slip which cuts across and disrupts bedding. Lithologic banding represents transposed remnants of beds. It is subparallel to but not coincident with cleavage. The intersection of cleavage and lithologic banding defines steeply plunging lines characterized by mineral streaks. Steeply plunging small folds are parallel to the intersection of bedding and cleavage. Orientations of structural and bedding surfaces control the orientation of steeply plunging intersections. Large isoclinal folds in bedding have subhorizontal axes. The mean orientation of cleavage parallels the axial planes of these folds. Plots of cleavage orientations on equal-area projections, however, indicate that the intersections of cleavages, or axes of variation, are nearly vertical. Because the cleavage axes are nearly perpendicular to the major fold axes, cleavage intersects bedding in nearly vertical lines on the steep limbs of the original folds. By inference, after isoclinal folding of bedding, the rock mass flattened perpendicular to the axial planes and extended laterally by differential, strike-slip movements on cleavage.

FeS_2-NiS_2 PHASE RELATIONS

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The phase relations between pyrite (FeS_2) and vaesite (NiS_2) were studied in the presence of a sulfur-rich liquid and a vapor. The solid solutions between these phases reach maxima of about 7 weight per cent NiS_2 in FeS_2 and 28.3 weight per cent FeS_2 in NiS_2. No intermediate compound corresponding to the mineral bravoite was encountered. These maxima occur at 729 ± 3°C., which is the invariant temperature above which pyrite and vaesite cannot coexist, and the stable assem-

blages are pyrite–$(Fe,Ni)_{1-x}$ S–liquid–vapor, and vaesite–$(Fe,Ni)_{1-x}$ S–liquid–vapor. The solidus curves extend from the solid solution maxima up to the melting points of the pure compounds (pyrite, incongruent at 743 ± 3° C.; vaesite, congruent at ~1010°C.). At temperatures below 729° C. the FeS_2 solid solubility in vaesite decreases quickly: 700° C., 24.2 wt. %; 600° C., 13.8 %; 500° C., 10.0%; and 400° C., ~ 9.4%. The pyrite solvus is steep; its determination is hampered by metastable solution of NiS_2 beyond the equilibrium amount, and extremely slow exsolution rates.

The cell value for pure pyrite of a = 5.417 Å increases as a linear function of composition to about 5.433 Å with 7 wt. % NiS_2. The variation in the vaesite cell is also linear from 5.688 Å in pure NiS_2 to 5.604 Å with 28.3 % FeS_2 in solid solution.

The vaesite solvus is ideally suited for determination of formation temperatures in naturally occurring pyrite-vaesite assemblages. It is suggested that the reported occurrences of the mineral "bravoite" may be vaesite solid solutions or mechanical mixtures of pyrite and vaesite.

IRON-RICH PORTION OF THE SYSTEM Fe-Ni-S

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Part of the system Fe-Ni-S is being studied as the beginning of an experimental investigation of systems important to the understanding of phase equilibria in the iron meteorites. Charges were prepared by mixing sulfur with five iron-nickel alloys containing up to 25 weight per cent nickel in 5 per cent intervals and one alloy containing 38.6 weight per cent nickel. Bulk compositions of the charges lay between the join FeS-NiS and the join Fe-Ni. The system was investigated in evacuated silica tubes between 600°C. and 1000°C. by quenching methods.

Contours on the liquidus were located at 900°C. and 1000°C. The temperature of the liquidus in the part of the system in which the primary solid phase is a metal is very sensitive to the amount of sulfur present; changing the sulfur content by 1 per cent changes the temperature of the liquidus by about 100°C. Below 988° C. alloy, monosulfide, and liquid can coexist stably. The liquid in equilibrium with alloy and troilite is slightly richer in nickel than the metallic phase. The sulfide in equilibrium with alloy and liquid contains less than 1 per cent nickel at 900° C.

Runs in the subsolidus part of the system have yielded only alloys and monosulfide in the range of compositions studied. Pentlandite has not been encountered. A small but measurable amount of nickel enters the sulfide, and this amount depends on the temperature. The nickel content of the troilite can thus give information about the conditions under which the meteorites formed.

GROUND WATER IN THE OAK SPRING FORMATION AND HYDROLOGIC EFFECTS OF UNDERGROUND NUCLEAR EXPLOSIONS AT THE NEVADA TEST SITE

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Several zones of perched ground water have been defined in tuff of the Oak Spring formation near the explosion sites. The Rainier test took place in a unit stratigraphically above a thin, probably discontinuous zone of perched water. The tunnel system for the Logan and Blanca experiments encountered ground water and acted as a drain until the Logan explosion, when flow ceased. Approximately 30 acre feet of water drained from this tunnel system in about 7 weeks. The Logan site was at or near a perched water table; the Blanca site was above the same perched water table. The water has a relatively high concentration of silica but is otherwise low in dissolved solids, and the level of radioactivity is low.

Hydrologic effects of the explosions involve changes in rock characteristics that directly or indirectly control (1) volume of water in storage, (2) rate and direction of ground-water movement,

and (3) chemical and radiochemical equilibrium between the rock and its contained water. The radius of effect is small compared to the probable areal extent of the perched water zone. Water samples from the zone affected by the Logan explosion and leaching experiments on other radioactive rock indicate that some fission products are taken into solution by percolating ground water. A probably slow rate of ground-water movement, low solubility of the explosion-produced glass, and lag effects due to ion adsorption tend to retard movement of contaminants from the sites. The remoteness of the area further reduces the risk of off-site contamination.

BLACK-SHALE FLYSCH FACIES OF THE OUACHITA MOUNTAINS, SOUTHEASTERN OKLAHOMA

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The sedimentary features of the upper Mississippian and lower Pennsylvanian Stanley-Jackfork-Johns Valley-Atoka stratigraphic sequence of the Ouachita Mountains of Oklahoma are comparable to the typical black-shale flysch facies of the Eocene and Cretaceous of the Alps and Carpathian Mountains of Europe. The conclusion is reached that a predominately deep-water black-shale and radiolarian-chert environment was periodically interrupted by turbidity currents which debouched quartzose sands derived from a nearby shelf environment. The presence of convolute bedding, graded contacts of sandstones and overlying shales, abundant flow casts, flute casts, and groove casts on the under surfaces of the sandstones, the general lack of cross-bedding and ripple marks, and the scarcity of fossils except for planktonic and nektonic forms support this thesis. The most characteristic feature of the Stanley-Jackfork sequence is the repeated alternation of unfossiliferous dark shales and gray sandstones. The boulder-bearing Johns Valley shale represents what Alpine geologists call *wild flysch;* most of its limestone erratics are depositional rather than tectonic in origin.

The cherts and the graptolitic shales of the lower Paleozoic represent a period of very slow sedimentation in a deep and starved arcuate trough. The 22,000 feet of post-Arkansas novaculite sediments represents a period of rapid sedimentation during active tectonism.

The Johns Valley shale lies stratigraphically above the Jackfork group, and it contains late Mississippian marine invertebrates indigenous to the lower part of the formation; thus, the entire Stanley-Jackfork sequence is pre-Pennsylvanian.

GEOLOGY OF THE MT. VELMA QUADRANGLE, ELKO COUNTY, NEVADA*

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Rocks exposed in the Mt. Velma quadrangle are chiefly Cenozoic volcanic rocks and several sedimentary formations which apparently belong to the "overlap assemblage" of the upper Paleozoic in north-central Nevada. Beds of volcanic and sedimentary origin of Triassic(?) age lie between these in the south-central part of the quadrangle. In the northern part of the quadrangle, the "overlap assemblage" lies upon probable lower Paleozoic sediments belonging to the "eastern assemblage", but in one locality upon cherts of the "western assemblage". Late Cretaceous (?) intrusions were followed by uplift and erosion during the early Cenozoic. Extensive coarse gravels underlie volcanic rocks which were extruded during at least two periods in the middle or late Cenozoic. The volcanic rocks exhibit strong folding in the northern part of the quadrangle. The folding was accompanied or followed by normal faulting. These northeast-trending faults are cut by a more prominent set of northwest-trending normal faults (parallel to the major basins and ranges of the area). Partially consolidated gravels in terraces show some effects of faulting and tilting. These are now being incised by streams well adjusted to lithology and structure.

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GEOHYDROLOGIC RELATIONSHIPS IN SMALL DRAINAGE BASINS OF NEW YORK

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Although important advances have been made in the last 15 years in the fields of quantitative geomorphology and watershed hydrology, many gaps remain in knowledge of their relationships. The U. S. Geological Survey has been engaged in studies to eliminate these gaps through analysis of geomorphic and geologic controls of the low-flow end of the stream-discharge spectrum.

Thirteen drainage basins, nine in the Catskill Mountains and four in central New York, ranging in size from 14 to 66 square miles, were studied. Geomorphic data were compiled from 1:62,500 scale topographic maps. Sandstone–silstone ratios, amount of stratified alluvium and outwash, and well and spring characteristics were measured in the field. Hydrologic analyses consisted mainly of calculation of stream base-flow-recession indices. New parameters such as mean stream relief, storm runoff depletion time, base-flow depletion rate, and an index of available storage were developed to test geohydrologic relations. Direct correlation exists between hydrologic characteristics and the parameters of sandstone–siltstone ratios, basin and stream relief, and topographic and stream slopes.

The Catskill basins have greater relief, steeper topographic and stream slopes, higher sandstone–siltstone ratios, lower stream density, and less area of valley fill than the central New York basins. The Catskill basins have greater rainfall and discharge per square mile and lower storm and groundwater depletion rates than the other basins. Apparently, in the Catskill basins, valley fill is commonly less permeable and contributes less water to stream flow than does the bedrock.

GENESIS OF JADEITE FROM SAN BENITO COUNTY, CALIFORNIA

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Tectonic inclusions within the New Idria serpentine body contain jadeite in two distinct environments. Lenslike inclusions 10 by 30 feet have a central monomineralic core of green jadeite (jd 75, ac 15, di 10) surrounded by a calc-silicate zone containing pectolite and hydrogrossular (2.25-3 moles H_2O) with minor sphene, aragonite, and chlorite. Analyses of the calc-silicate zone show low SiO_2 (37.2 per cent), Na_2O (2.8 per cent), and high CaO (25.9 per cent) with 3.4 per cent BaO and 0.31 per cent B. The peculiar composition and apparent stability of hydrogrossular-pectolite in association with jadeite suggests that the P-T conditions during the formation of this jadeite are considerably below those found by current experimental data. Jadeite (jd 98, ac 1, di 1) also occurs in veins which show crosscutting relations along the periphery of albite-crossite schist inclusions. Jadeite coexists with minor amounts of low albite (An_2) in these veins, and both jadeite and acmite coexist with low albite (An_{1-2}) within the host schist. Locally both the albite and jadeite are replaced by analcite. The high Na_2O (9.8 per cent) and low SiO_2 (64.8 per cent) of the albite–crossite schist indicate that the formation of jadeite in this rock may result more from an unusual composition that from extremely high pressures.

As pectolite is ubiquitous in these rocks to the exclusion of lawsonite, it seems that lower water pressures prevailed in this environment than are assumed for the jadeite–lawsonite–quartz assemblage. Considering this geological observation, Fyfe and Valpy suggest a low-temperature environment may favor the formation of jadeite if $P_{H_2O} < P_t$.

EXPERIMENTS ON SURFACE AND STRAIN ENERGY IN MINERALS

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A twin calorimeter made of polythene, and of new design, was used to measure the heats of solution at 40°C. of various grain sizes of quartz, silica glass, calcite, precipitated $CaCO_3$, and fluorapatite, with a standard error of less than 0.6%.

1. The enthalpy change (ΔH) and the adiabatic temperature rise (ΔT) for isochemical recrystallization at 40°C. from −200+250 (Tyler) mesh to −48+65 mesh were calculated to be as follows:

	ΔH cal/mole.	ΔT°C
Quartz	1160	107
Calcite	853	42
Fluorapatite	2609	26

2. The enthalpy change for devitrificationof silica glass at 40°C. was calculated to be approximately 5000 calories per mole, and the accompanying adiabatic temperature rise 480°C.

3. Samples of silica and of calcite were kept under a confining pressure of 24,000 p.s.i. for 24 hours, at various temperatures, and their heats of solution measured. Comparison with heats of solution obtained earlier indicated that:

i. quartz recrystallized 0.96 per cent at 700°C.,
ii. calcite recrystallized 29 per cent at 530°C., and
iii. silica glass devitrified 2 per cent at 270°C., 8 per cent at 530°C., and 80 per cent at 700°C.

4. The maximum strain energy held by calcite and quartz was estimated for several grain sizes of each.

SUCCESSFUL APPLICATION OF SHEAR IN SYNTHESIZING HIGH-PRESSURE FORMS OF SEVERAL PHASES

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Although shear phenomena have an important place in geological processes, experiments like those of Larsen and Bridgman failed to synthesize high-pressure "stress" minerals. However, in 1956 Burns and Bredig reported the formation of aragonite by simply grinding calcite in a mortar. This experiment has been repeated and fully confirmed. The reverse reaction could not be achieved under similar conditions.

P-T curves determined in this laboratory for the transformations of PbO_2 I $\rightleftharpoons$ II (W. B. White) and MnF_2 I $\rightleftharpoons$ II (L. M. Azzaria) are of interest here. The low-pressure forms are rutile structures, and the high-pressure forms probably have analogous orthorhombic structures. The curves pass through points at 15,000 atm and 500°C. for PbO_2 and 13,500 atm and 500°C. for MnF_2. At room temperatures equilibrium pressures are close to 11,000 and 9000 atm for the PbO_2 and MnF_2 respectively. Both these transformations have been made to proceed in the up-pressure direction by merely grinding in a mechanical shaker and in a mortar.

A fourth example of a similar reaction is the reversible transformation of PbO (litharge $\rightleftharpoons$ massicot) in the same type of grinding experiments. Because of exceptional P-T relations (W. B. White) litharge transforms to massicot at 2500 atm and 300°C., but the pressure necessary at room temperature is 9000 atm.

It has not been possible to convert SiO_2 and BeF_2 into the coesite modifications or force the metastable $GeO_{2\ quartz}$ into the rutile form under such shearing conditions. The effect of more intense conditions and longer time intervals on these and alumino-silicates is being studied.

TRACE FERRIDES IN IRON ORES FROM THE IRON SPRINGS DISTRICT, UTAH

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Investigation of the trace ferrides cobalt, manganese, nickel, titanium, and vanadium was made on samples of ore collected from accessible iron deposits associated with three monzonite porphyry intrusions in the Iron Springs district, Utah.

Iron-mineral grains were separated and spectrochemically analyzed on a 1.5 meter, 24,400 lines per inch grating, Abney mount spectrograph. Iron was the variable internal standard.

Polished sections of separated iron grains of all samples collected were studied, and mineral relationships and the percentages of magnetite, hematite, limonite, and sulfides were determined.

Quantitative data obtained were subjected to statistical analyses. The results of the analyses revealed several specific relationships:

1. The trace ferrides are of the same primary genetic population, based on similar abundances of cobalt, titanium, and vanadium.
2. The degree of oxidation of the iron ores in the Iron Mountain area is significantly different from that of the iron ores in the Granite Mountain-Desert and Three Peaks areas.
3. Manganese and nickel from the iron ores of the Granite Mountain-Desert and Three Peaks areas belong to one statistical population, whereas those of the Iron Mountain area belong to another statistical population. This relationship and the state of oxidation of the iron ores are apparently related. In the more oxidized areas, nickel has been enriched, and manganese has been impoverished.

LAND SUBSIDENCE, RELATED TO DECLINE OF ARTESIAN HEAD IN THE OCALA LIMESTONE AT SAVANNAH, GEORGIA

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Precise leveling by the Coast and Geodetic Survey in 1918, 1933, 1935, and 1955 indicates that the land surface has subsided as much as 4 inches in the Savannah, Georgia, area. Comparison of level lines of different periods indicates that most of the subsidence has taken place since 1933.

Ground-water withdrawals from the Ocala and associated limestones of Eocene age increased gradually from a rate of 6 million gallons per day in 1888 to 20 mgd in 1936, but then nearly tripled to 57 mgd by 1955. The artesian head of the confined limestone aquifer has declined sharply in response to the greatly increased withdrawal since 1936. The head declined about 50 feet in the 48 years before 1936, and as much as 85 feet more in the 19 years from 1936 through 1955. If it is postulated that the artesian pressure supports part of the load of the confining bed and overlying deposits, then the decrease in artesian head has been accompanied by an increase of effective stress on the aquifer rock. In support of this postulate, the area affected by subsidence corresponds closely with the area of large decline in head, and most of the subsidence occurred during the period of rapid head decline from 1936 to 1955. This close agreement in time of occurrence and areal extent indicates that the decline of artesian head is a major, if not the principal, cause of land subsidence in the Savannah area.

SULFUR ISOTOPES AND THE ORIGIN OF THE HEATH STEELE ORE DEPOSITS, NEW BRUNSWICK, CANADA

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Middle Ordovician Tetagouche group rocks in the Heath Steele mines, New Brunswick, Canada, area form a steeply plunging recumbent anticline. The ore deposits of Zn, Cu, and Pb are associated with minor folding and/or sheared dilatant zones at or near the contact between sericitic schist and quartz-feldspar porphyry.

Sulfur isotopic ratios have been determined at Yale University for more than 500 sulfide and sulfate specimens from New Brunswick. Some 150 analyses are of samples from the several mines of the Heath Steele property (and adjacent country rock) for which primary and secondary (supergene) ore sulfides exhibit similar values that average about 21.9 in S^{32}/S^{34} ratio ($\delta S^{34}‰ = +14.0$). The enrichment of S^{34} in the ore sulfides and the presence of graphite, evident from mineralographic studies and mass spectrometric analyses, suggest reduction of original sulfates at temperatures in excess of 500°–600°C. during the creation of a magma from which it is inferred the ore solutions were derived.

Magmatic hydrothermal solutions presumably become concentrated and thereby homogenized in the latest crystallizing phase of intrusive bodies, whereas metamorphic hydrothermal solutions derived from heterogeneous sources may never have a chance of extensive intermingling before mineral deposition occurs. S^{32}/S^{34} analyses of nonore sulfides collected from country rock throughout northern New Brunswick range between 21.9 and 22.7 and average about 22.3 in ratio. In comparison, the average of sulfide ore samples is about 21.9 and for the Heath Steele mines ranges only between 21.82 and 22.02, which suggests a well-homogenized, magmatic hydrothermal source of ore (sulfur) solutions.

STRUCTURE AND TECTONIC HISTORY OF MEXICO

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Although Mexico's pre-Mesozoic basement is still poorly known, the late Precambrian hedreocraton of southwestern United States appears to have extended into Sonora, Chihuahua, and even to Tamaulipas, and received early Paleozoic miogeosynclinal sediments.

Judging from distribution of metamorphic rocks, the early Paleozoic Frazer belt extended southwestward from Nevada into westernmost Sonora and along the Pacific coast to southeastern Chiapas. The late Paleozoic Ouachita geosyncline continued southwestward from Texas into northeastern Mexico and swung southward and eastward into Chiapas and Yucatán, now covered by younger rocks. The entire Paleozoic basement became cratonal at the end of the Paleozoic.

The late Triassic–middle Jurassic molasse sedimentation was accompanied by taphrogeny and followed by late Jurassic–early Cretaceous eugeosynclinal sedimentation in Baja California and miogeosynclinal deposition elsewhere. Orogeny began in late Cenomanian time with granitoid intrusions in a belt 130 km wide along the Pacific coast, from northern Baja California to Chiapas, flanked by flysch sedimentation.

Mexico's present main structural features consisting of folds and minor faults resulted from early Eocene deformation of Mesozoic rocks against the west margin of the late Paleozoic craton. Late Eocene–Oligocene molasse sedimentation and taphrogeny, followed by Miocene subsequent volcanism, Pliocene bolson deposition, and Pleistocene basaltic volcanism complete the orogenic history. The trans-Mexico volcanic belt is a Pleistocene–Recent feature, superposed obliquely on the Laramide system.

LAMELLAR STRUCTURE IN A TYPE I DIAMOND

Reynolds M. Denning

A polished rectangular parallelopiped of a very pale-yellow type I diamond, which shows between crossed polars a pronounced octahedral lamellar structure, was studied by several methods. The birefringent lamellae (birefringence 2×10^{-5}) show extinction bands that move as the crystal is rotated. Some lamellae are length fast, others are length slow. Fluorescence in the diamond is strongest in the more birefringent regions. Likewise X-ray scattering is strongest in the birefringent regions of the crystal. All portions are opaque in the spectral region from 7μ to 9μ. Also it is opaque below $315m\mu$.

Grinding behavior and X rays fail to reveal twinning. The lamellae are the result of strain induced by periodic variation during the growth of the crystal. If the lamellar structure is due to the variation of nitrogen content, as suggested recently by Kaiser and Bond, then the diamond has a concentration of nitrogen greater than 3.5×10^{20} atoms/cm^3. A central nonlamellar nucleus shows a birefringence of 10^{-4}, which seems too great to be explained by nitrogen substitution alone. Probably the cause of birefringence in the latter instance is due to an additional substitution or perhaps to an entirely different mechanism.

EVIDENCE OF THE ORIGIN OF BLIND RIVER URANIUM DEPOSITS—A PROGRESS REPORT

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The paper, a co-ordination of data rather than original research, was first prepared for the November 1958 meeting but was withdrawn due to the absence of the author. It is now revised to include later evidence from studies of the area, and of the 10 mines now in full production, from sources including Government reports, studies by mine geologists, and research for post-graduate degrees.

The main facts established are:

(1) Commercial ore is mainly restricted to certain quartz-pebble conglomerate beds included in predominantly quartzitic Lower Huronian sediments, and there is a direct relationship between maximum conglomerate development and grade of uranium.

(2) The source of the detrital material was from the basement rocks to the northwest.

(3) The ore minerals are uraninite and brannerite in a variable proportion, and in forms unlikely to be preserved as detrital grains.

(4) Age determinations show that definite detrital minerals have an age corresponding to that of the Archean basement, while the uranium minerals have an age close to that of the deposition of the Lower Huronian sediments.

It is concluded that:

(1) The quartz-pebble conglomerates were deposited at least 1700 m.y. ago in estuaries of rivers carrying material from an older landmass to the northwest.

(2) Uranium minerals in their present form were deposited contemporaneously with, or shortly after, deposition of the beds not as detrital material but by precipitation from supergene solutions.

(3) Hydrothermal action does not appear to have played a more significant part than minor redistribution of the uranium especially in the vicinity of diabase dikes.

CORRELATION OF COAL BEDS BY CHEMICAL, PHYSICAL, PETROGRAPHIC, AND PALYNOLOGICAL TECHNIQUES

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Review of the literature of the past few years shows that only a few isolated attempts have been made to correlate coal beds by chemical and physical techniques. Successful correlations using these techniques are possible depending on establishment of valid criteria for correlation and organization of a logical operational procedure.

Reports of successful correlations of coal beds by petrographic means are few. Two conditions must be satisfied: distinctive depositional environments must have been widespread and have led to widespread layers of recognizable petrographic character, and (or) different successions of environments must have characterized each coal swamp. Fulfilment of both conditions allows the correlation of petrographic profiles in the form of "brightness" histograms. Fulfilment of only the first condition allows correlation by distinctive marker layers, such as clayey bands and durain bands. Few vitrain or fusain layers are continuous enough to be used for correlation.

Correlation of coal beds on the basis of included plant spores was first attempted in the 1920's using spores recognized in thin sections of coal. Most subsequent studies have utilized macerated materials; the spores observed have been isolated from samples of coal by chemical and physical treatment. Various techniques of sampling and preparation are used, and correlations are based either on the total aspect of the spore assemblage or on individual spore types considered to be guides to a single bed or to a biostratigraphic zone. Recent papers have re-examined basic concepts and have explored statistical methods in attempting to achieve greater precision and usefulness.

IMPLICATIONS OF THE COMPOSITIONAL ADJUSTMENTS REQUIRED AT CRYSTAL SURFACES

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Compositional adjustments to satisfy valence and ion co-ordination demands and missing atoms on surfaces of some minerals produce surface compositions different from the crystal composition. These are the compositions involved with disperse phase reactions and grain contacts. The type of surface solution adopted would be determined in part by the environmental factors. Consequently, as the surface solution adopted varies, the surface energies and surface chemistries produced and their effects on crystal growth, nucleation, ion exchange, catalysis, *etc.*, also would vary.

For example if additional H and Mg balance charges and water groups complete ion co-ordinations, possible phlogopite (010)–(110) surface compositions are: K H $Mg_{3.66}H_4Al_2Si_6H_4O_{22}(OH)_{2.33}$; or various combinations such as: K H $Mg_{5.66}Al_2Si_6H_4O_{22}(OH)_{2.33}(H_2O)_{5.33}$; or combinations with various cation substitutions within the crystal.

During growth, water and H become the exchangeable atoms for growth materials. Whatever solution is adopted, mica crystal growth normal to c is essentially a process of converting the amphibole-like surfaces to mica composition. Accordingly, mica could nucleate on amphibole surfaces and *vice versa*. Except for (001), amphibole surfaces are essentially of amphibole composition.

Four compositions are present on the various kaolinite (010)–(110) surfaces of a single crystal with adjacent and opposite faces around the "hexagonal" plate of different compositions. This could cause differential absorptions and could explain the differential growth rates of these faces on some crystals.

Various mineral associations and growth relations are correlated with such surface features.

MULTIPLE TWINNING IN $BaTiO_3$

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The purpose of this paper is: (1) to describe a unique form of multiple spinel-type growth twinning in $BaTiO_3$; (2) to propose some ideas relative to its origin; and (3) to call attention to the type of packing of TiO_6 octahedra associated with multiple twinning in the perovskite structure as deduced from a hard sphere model.

Multiple twin crystals with three (111) twinning planes are found occasionally in crystal growth runs in the system KF-$BaTiO_3$. The twinned crystals grow in the form of flat (100) plates alternating right and left along a common spine. An interpretation of the morphological features suggests that the crystal grows from a nucleus which contains all the twinning elements and not by repeated twinning followed by periods of growth. All the multiple twin forms can be described in terms of simple arrangements of face-sharing TiO_6 octahedra. It is suggested from these units and the types of crystals seen that there is a maximum of two shared faces per TiO_6 octahedron and that certain faces of two octahedra in twinned relationship are more likely than others to participate in face-shared groups.

MAXIMUM ACCELERATIONS CAUSED BY UNDERGROUND NUCLEAR EXPLOSIONS IN THE OAK SPRING FORMATION AT THE NEVADA TEST SITE

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Preliminary analyses of the ground motion due to underground nuclear explosions in the bedded volcanic tuff of the Oak Spring formation in Area 12 of the Nevada Test Site indicate the maximum single-component acceleration scales as:

$$A = \frac{(0.6 \pm 0.5)W^{0.8\pm0.2}}{D^{2\pm0.2}}$$

where A is the maximum acceleration of the ground in units of gravity caused by an explosion of W kilotons yield at a distance of D km from the explosion. Higher rates of attenuation of acceleration with distance were found closer than 5 km from the explosions by other investigators.

The large standard deviation of the scaling coefficient (0.6 ± 0.5) in the scaling relation reflects mainly the effect of local geologic conditions about the recording stations and the degree of containment of the explosions. Maximum accelerations recorded on deep alluvium are several times higher than those recorded on tuff or bedrock. The maximum accelerations due to the better contained explosions seem to be significantly higher than those generated by the less well-contained explosions.

A preliminary comparison of the maximum accelerations caused by explosions in air over Yucca Flat and the underground explosions in Area 12 indicates that the underground explosions produce maximum accelerations roughly 10 times greater than explosions of the same yield 500 to 750 feet above the ground.

FORMATION OF ZEOLITES BY THE ALTERATION OF A VOLCANIC GLASS BY ALKALINE SOLUTIONS

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Volcanic glasses are the principal parent materials of natural zeolites, and the large zeolite deposits of the world are alteration products of pyroclastic rocks. A study of the alteration of a siliceous vol-

canic glass by alkaline solutions was made to obtain information on the nature of zeolite formation in volcanic rocks.

The alteration of a rhyolite glass by solutions of $NaOH$-$NaAlO_2$ and Na_2CO_3-$NaAlO_2$ was carried out at 100°C. at atmospheric pressure for 1, 7, 21, and 30 days. In some runs mixtures of trona and gibbsite were used in the solutions. Analcime, phillipsite types, faujasite, and zeolite A were produced along with cancrinite and sodalite. Gibbsite was produced as a coexisting phase in some runs. Where albite, microcline, and nepheline were used as starting materials, reaction rates were slower, and only sodalite, analcime, gibbsite, and the cubic phillipsite appeared as synthetic phases.

These studies suggest that zeolite A may be found in nature where volcanic glass has been altered by alkaline solutions. Also suggested by the experimental results is the formation of marine phillipsite by the alteration of volcanic ash.

STRATIGRAPHY AND ORGANIC SUBSTANCES OF MIDDLE AND UPPER DEVONIAN, ORBISONIA QUADRANGLE, PENNSYLVANIA

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Middle Devonian rocks of Orbisonia quadrangle, central Pennsylvania, include in ascending order: Newton Hamilton formation (Lower Devonian?), containing Beaverdam dark shale member below and Hares Valley shale and shaly limestone member above (100+ feet), represents Onondaga group; Marcellus black shale (175+ feet) and Mahantango fossiliferous gray shale, siltstone, and subgraywacke (1175–1550 feet) represent Hamilton group. Two mappable ridge-forming sandstone-siltstone units and a single thin red protoquartzite occur in Mahantango.

Upper Devonian of area consists of: Harrell platy, silty, near-shore shale (160–300 feet), with intertonguing micaceous lutite unit, Burket "black shale" (100 feet) at base, which owes dark color to finely divided mica rather than to organic matter; Brallier formation, more than 2000 feet of greenish slabby siltstone, mainly unfossiliferous, represents Portage group. No Tully found in area, and Burket apparently unconformable on Mahantango. Chocolate-red layers beginning 1000 feet above base of Brallier mark early effects of Acadian disturbance here. Overlying Chemung group comprises partly fossiliferous maroon shale, siltstones, gray shales, and sandstones also more than 2000 feet thick, overlain by Catskill red beds, incompletely exposed in quadrangle.

Clay-sized fractions of Devonian rocks here consist of mainly muscovite, sericite, and chlorite rather than of clay minerals.

Acid hydrolyzates of Burket lutite yielded suite of amino acids including: lysine, arginine or histidine, aspartic acid or glycine, threonine, glutamic acid, alanine, tyrosine, valine, phenylalanine, and leucine. A few amino acids are also found in Newton Hamilton. Hydrocarbons and carbohydrate degradation products also are being studied.

ANALYSIS OF PALEOMAGNETIC DATA

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Conclusions drawn from paleomagnetic data concerning continental drift, continental rotations, and polar wandering depend critically upon the statistical treatment used. A recalculation of all available paleomagnetic data, using where possible appropriate homogeneous statistical standards, has led to the following general conclusions. As has been pointed out by other workers, the magnetic poles calculated for formations of post-early Tertiary age from all continents rarely differ significantly from the present geographic pole; however, most magnetic-pole positions determined for older forma-

tions are significantly different. Paleomagnetic results from Mesozoic and lower Tertiary rocks have recently been interpreted in terms of continental rotations and displacements of thousands of kilometers. An alternate hypothesis—that during this period the earth's magnetic field was a comparatively rapidly changing dipole—correlates these results without requiring displacements of continents. Moreover this interpretation does not require the synchronous rotation of India and Oregon, as is needed for the drift hypothesis.

CRETACEOUS FLORA FROM BEDS ASSOCIATED WITH RUBBLE IRON-ORE DEPOSITS IN THE LABRADOR TROUGH

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A collection of fossil leaves has been made from a bed of hard, ferruginous argillite associated with rubble ores at the Redmond No. 1 deposit in the Knob Lake district of Labrador. The well-preserved floral remains consist of 36 species, including 1 alga, 4 ferns, 1 lycopod, 3 conifers, and 27 species of angiosperms. The depositional setting of the flora is believed to have been a shallow lacustrine basin in a humid, warm-temperate climate. Most of the plant species have been previously reported from Cretaceous floras of United States, Canada, and Greenland. Closest correlatives are the Raritan flora of New Jersey, the Dakota flora of the Great Plains, and the Tuscaloosa flora of Alabama. These are generally interpreted to be of early Late Cretaceous age.

The rubble ores adjacent to the fossil-bearing bed are believed also to be of Cretaceous age. There is no evidence that the underlying protores are not of Precambrian age as presently assigned. The tilting and faulting of the plant-bearing bed indicate an episode of deformation in the Labrador region some time after early Late Cretaceous time.

FAULTING ALONG APPALACHIAN FRONT, CENTRAL PENNSYLVANIA

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Reconnaissance of the northwesternmost ridge of the Appalachian fold belt shows that faults are much more numerous than hitherto reported. Steeply dipping to vertical faults oriented essentially normal to the ridge crest are indicated by abrupt horizontal offsets of topographic and stratigraphic elements, by sharp topographic lows, and by concentrations of brecciated and slickensided float. At least 30 such transverse faults are present along Bald Eagle Mountain. Horizontal offsets of 300–2500 feet show, in all but one instance, relative displacement of northeast side south. Quarry exposures of more numerous, smaller faults on Dunning Mountain reveal slickensides inclined toward the northwest at various angles.

Between the main crest of Bald Eagle Mountain, upheld by Tuscarora and Juniata strata, and the subsidiary ridge on the southeastern flank, upheld by Oswego strata, the presence of major, generally longitudinal faults is suggested by divergence of homoclinal ridges and variations in width of outcrop of the Juniata without apparent compensating changes in dip, and by major transverse faults not traceable across both ridges. Minor longitudinal faults are exposed in Dunning Mountain quarries and at McKee and Tyrone gaps.

The transverse faults are parallel to a joint set present both in overturned strata on the ridge crest and in upright strata in the flanking valleys. This relationship, plus slickenside orientation, suggests that faulting occurred late in the deformational history of the region during overturning and partial collapse of the Nittany arch. Longitudinal faulting is believed to have occurred at almost the same time.

TILLITE OR SUBAQUEOUS SLIDE?

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Rhythmically laminated sandstone-siltstone-mudstone associated with unsorted boulder beds have been interpreted as glacial varves and tillites respectively. Elaborate theories of ancient climatology and geotectonics are still erected upon this foundation. Mass flows and suspensions of sediment moving downward under influence of gravity provide means of retransporting shallow marine or terrigenous clastic sediments and organic remains to "foreign" environments. Much repetitious graded bedding was not satisfactorily explained until these mechanisms were evaluated in Mesozoic–Cenozoic deposits in geosynclines and modern oceans.

By analogy with submarine-slide deposits of California and Oregon, it is reasoned that the famous Squantum "tillite" near Boston, Massachusetts, possesses so many similarities of composition, sedimentary features, gross stratigraphy, and tectonic setting as to make the glacial interpretation suspect. Periodic subaqueous sliding of rapidly deposited, volcanic-rich sediments in a mid-Paleozoic eugeosynclinal belt is proposed as an alternate hypothesis. Absolute criteria for distinction of sliding from glacial processes are difficult to discover, however. Both produce very poor sorting of clasts; both can conceivably produce faceting and striation of pebbles. Only a preserved glacial pavement overlain by extensive, poorly sorted, nonmarine till-like material, as in South Africa and India, seems unequivocal. General stratigraphic relations and tectonic setting serve as secondary factors in judging probability of sliding in many geosynclinal sequences. Several other examples have been challenged recently so that clearly most ancient "tillites" and glacial periods must be regarded with suspicion until critically reanalyzed.

SIGNIFICANCE OF TILL-FABRIC INVESTIGATIONS IN REGIONAL AND STRATIGRAPHIC PLEISTOCENE STUDIES

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Deciphering glacial movements by routine till-fabric investigations is apparently not so common as measuring glacial striae or linear topographic forms. In areas with several till layers, fabric studies provide the most detailed information on glacial movements and their changes. As fabric has to be determined in many scattered locations or at several depths, rapid two-dimensional field or laboratory measurements of alignment of 50 pebbles, requiring ½ to 1 hour per site, are preferred to the more precise but time-consuming three-dimensional studies.

Some examples of application of till-fabric studies, cross-checked by striae and/or till lithology, are:

(1) An earlier N.-S. fabric till was distinguished from a later, W.-SW. fabric till in the Pigeon River area, northwest of Lake Superior, and three tills with different fabrics and belonging to three different lobes were distinguished at London, Ontario.

(2) Deciphering origin of drumlins: Some drumlin fields of Southern Ontario have cores of older till in which the fabric differs up to 90° from the alignment of the drumlins. Till fabric reveals that the western portion of a S.-SW. trending drumlin field at Port Elgin, Ontario, has been later overridden by the Huron lobe from the northwest.

(3) Gradual changes of alignment of pebbles through more than 90° in a vertical sequence have been found in several thick till layers in Southern Ontario, suggesting considerable reorientation of glacial movement in one lobe.

Systematic till-fabric measurements should become a routine procedure in Pleistocene regional mapping of areas with multiple or thick tills.

ATTAPULGITE IN LACUSTRINE SEDIMENTS OF SOUTHERN CALIFORNIA*

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Attapulgite veins occur in lacustrine and alluvial sediments and basalt of the Tropico group (Tertiary age) in the Four Corners area, San Bernardino and Kern counties, California. X-ray, chemical, and optical data indicate that attapulgite is the principal clay mineral in much of the vein material. Montmorillonite, dolomite, and quartz are minor constituents (less than 10 per cent). Attapulgite veins consist of white, dense, hard, brittle fibrous material and may have a thin (less than 0.1 mm) coating of red and brown iron oxide at the contact of the vein and the wall rock. The veins range in thickness from less than 0.1 mm to 3.0 mm and are oriented at right angles to bedding.

The clay-mineral composition of claystone adjacent to the veins is montmorillonite (70 to 80 per cent), illite (20 to 30 per cent), and trace amounts of illite-montmorillonite mixed layers and chlorite and kaolinite. The nonclay minerals in the wall rock are quartz, feldspars, micas, calcite, and zeolites.

Although these veins are obviously secondary features, the genesis of the attapulgite is not clearly understood. The high purity of attapulgite and its association with dolomite suggest a low-temperature hydrothermal origin for the veins.

JASPEROID AND ORE DEPOSITS IN THE TINTIC AND EAST TINTIC MINING DISTRICTS, UTAH

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This investigation was conducted to determine the relationships of jasperoid masses to ore bodies in the Tintic and East Tintic mining districts of Utah. Samples were collected from surface exposures, diamond-drill cores, and several mines.

Minerals and textures were determined petrographically in 118 thin sections. In addition, semiquantitative spectrographic analyses were obtained for 37 elements in 55 of the samples and for 10 elements in 63 of the samples. The data were studied to determine differences between jasperoids associated with known ore deposits (productive jasperoid) and jasperoid masses isolated from ore deposits (barren jasperoid). Both the petrographic and spectrographic studies indicated differences between the two types of occurrences.

Petrographic work has shown that textural features such as relict microbrecciation, vugginess, and variable silica grain size are more common in productive jasperoids. The presence of sulfides, barite, sericite, clays, and hematite pseudomorphs after pyrite is indicative of proximity to ore. Barren jasperoids tend to be less porous than productive ones and are characterized by the presence of fibrous chalcedony and iron-oxide staining.

Spectrographic data indicate that antimony, bismuth, cadmium, copper, lead, silver, sodium, tantalum, and zinc are more abundant in productive jasperoids, and that calcium and magnesium are more common in barren jasperoids.

There are exceptions to these generalizations, but a statistical treatment of the data shows a significant variation between barren and productive jasperoids.

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DIFFERENTIAL THERMAL ANALYSIS OF GALENA AND CLAUSTHALITE

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Differential thermal analyses have been made on both natural and artificial lead-sulfur-selenium compounds. Thermal curves of 13 natural galenas and 1 clausthalite are given. The galena data in general exhibit a striking consistency regardless of the genetic associations of the minerals studied. In certain instances, slight variations in peak temperatures are shown to be related to lattice-parameter differences.

A 10 molecular per cent solid solution series from PbS to PbSe was formed by pyrosynthesis. X-ray measurements of unidimensional lattice variation with composition show a smooth curve. Thermal data, on the other hand, produce a more complex plot which is interpreted in terms of both lattice energies and the nature of the observed reactions. Annealing and slow cooling experiments provide no evidence of superlattice formation.

BOTTOM MARKS ON FIRM LUTITE SUBSTRATUM UNDERLYING TURBIDITE BEDS

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Three major classes of marks made on mud bottoms and generally preserved as negatives on soles of overlying turbidite beds are recognized: organic marks made prior to turbidite deposition, scour marks, and tool marks. These types may occur singly or in any combination; some of them furnish quantitative paleocurrent data and record flow conditions that prevailed as the turbidity current passed by.

Preservation of delicate organic markings made prior to turbidite deposition demonstrates that some turbidity currents deposited sediment without eroding the bottom at the site of deposition. Scour marks prove that bottom erosion preceded turbidite deposition. Tool marks, particularly impact marks, imply that particles were transported by saltation.

Bottom erosion does not occur where the current is just capable of transporting its entire load in suspension and lacks energy for scouring, or where a thick dense basal saltation load (here termed *saltation carpet*) prevents turbulent eddies of the higher part of the flow from contacting the lutite substratum. Scour marks are inferred to be products of currents whose entire load was transported in suspension and which possessed excess energy such that turbulent eddies of sediment-laden water could abrade the lutite. Mixed scour marks and impact marks suggest in addition that scattered saltating particles were present. Impact marks occurring alone signal the existence of a thin saltation carpet.

Both lateral "facies" changes in bottom-mark assemblages on a given surface and different generations of marks at any locality on it record changed flow conditions along the current traverse.

PLEISTOCENE (SALTAIR) CORE FROM GREAT SALT LAKE

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A continuous core was taken in Pleistocene sediments to a depth of 650 feet on the shore of Great Salt Lake about half way between the Oquirrh Mountains and Antelope Island. Of significance in the interpretation of the core were Ca and Mg carbonates, clay minerals, sand fractions, volcanic ashes, soils, laminations, oölites and fecal pellets, ostracodes, mollusks, and C14 dates. By integrating the several climatic indicators and other data the following conclusions were reached.

(1) The core is believed to have penetrated sediments deposited during the Wisconsin, Sangamon, Illinoian, Yarmouth, Kansan, and part of the Aftonian stages of the Pleistocene. Several soils represent hiatuses in the sedimentary record, but these were probably of short duration.

(2) The Wisconsin, as interpreted by C14 dates and rates of sedimentation, appears to be very long, having started about 185,000 years ago. It consists of two early pluvial episodes, then a long dry interstadial, then two short-lived lake intervals near the close. The Sangamon is calculated to have started about 245,000 years ago, the Illinoian about 308,000 years ago, the Yarmouth about 370,000 years ago, and the Kansan about 525,000 years ago.

(3) No relation of the pluvial stages of the core could be established to the Lake Bonneville beaches.

(4) There is little firm evidence by which to correlate the pluvial stages of the core with Rocky Mountain glacial stages.

(5) The Pearlette tuff at 548 feet is a significant time marker and, according to the succession of lakes recognized in the core, is early Kansan.

GEOLOGY APPLIED TO UNDERGROUND NUCLEAR TESTS

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The free world's first completely contained underground nuclear explosion, code name Rainier, took place in the tuff of the Oak Spring formation (Tertiary) at Nevada Test Site on September 17, 1957. Since then several other tests, some with much larger yields, have been successfully conducted in the same medium.

Since the inception of the underground test program the U. S. Geological Survey has acted as advisor to the Atomic Energy Commission and its contract organizations. Its advice has to do generally or specifically with the feasibility, in terms of public safety, of underground explosions. Escape of fission products, shock damage, and contamination of water supplies are of paramount importance.

The Survey's advice is based on detailed geologic investigations, highlights of which are presented in succeeding papers. Normal, but accelerated, field studies have been supplemented by quantities of laboratory data on chemical and physical properties of the rocks and by the results of two field tests using 10- and 50-ton charges of conventional high explosive.

LEAD ISOTOPES AND ORE DEPOSITION IN THE SOUTHEAST MISSOURI LEAD DISTRICT

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The Pb^{206}/Pb^{204} ratio in galena samples from the Southeast Missouri district ranges from 19.56 to 26.26 and appears to be due to variations in the radiogenic lead component of source solutions. At the Bonne Terre mine where the geologic relationships are relatively simple and maximum isotopic data are available, the lead-isotopic composition near ore channels is most radiogenic. In stratigraphically higher zones and at greater distances from the point of ore introduction the deposit contains progressively less radiogenic lead reflecting the sequential deposition of ore. The age of the source environment appears to be about 1400 m.y. based on the lead-isotopic data and a Rb-Sr age determination. The most probable mechanism for the formation of ore solutions appears to be inhomogeneous extraction of the lead from granitic rocks in the basement resulting, in the simple cases, in ore solutions with gradually increasing ratio of common rock lead/radiogenic lead.

The clear relationships between lead-isotopic composition and the distribution of the ore around an ore channel in Bonne Terre make it possible to suggest the location of ore channels and mineralization history in other parts of the Lead Belt where the geology is more complex.

FURTHER PROGRESS IN ABSOLUTE DATING OF THE MIDDLE ORDOVICIAN

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New age determinations based on uranium 238–lead 206 in zircons from four Middle Ordovician bentonites of eastern Tennessee confirm the measurements by the rubidium-strontium method on biotites from closely related samples reported at the 1958 meeting of the Society.

The new results show much greater precision than the earlier measurements. Samples from Alexandria, Dowelltown, and Nashville, Tennessee, all from Carters limestone of the Stone River group, yield ages of 452, 446, and 438 million years in comparison with 450 to 500 million years found in the earlier experiments. A sample from Vonore, Tennessee, from the Bays formation of the Middle Ordovician gives an age of 453 million years. The average of the latest measurements, 447 ±10 million years, is intermediate between the Holmes estimate of about 390 million years and the most extreme upward revision of the geological time scale that has been proposed during the past year.

PHASES OF THE CHAMPLAIN SEA INDICATED BY LITTORAL MOLLUSKS

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Littoral Champlain Sea deposits are found from 140 to 570 feet altitude near Montreal. *Macoma balthica* occurs throughout and tends to be larger at lower altitudes. Littoral *Hiatella arctica* occurs above 190 feet and decreases in weight as altitude decreases. *Mytilus edulis* is mainly above 180 feet and shows growth increments similar to modern shells in southern Hudson Bay. *Mya arenaria* is lower than 200 feet; shells are thin and lengthen downward from 18 to 42 mm at 140 feet.

The size and weight trends of this dwarf fauna, attributed by Goldring to salinity differences, also depend on temperatures. Comparison with modern shells shows that the littoral fauna above 200 feet represents a subarctic sea with summer temperatures from 0° to 5°C. and salinity from 28 to 23‰, which became warmer and fresher as it shoaled because of crustal warping; for this the term "*Hiatella* phase" is proposed. Littoral faunas below 200 feet indicate much warmer, less saline water for which the term "*Mya* phase" is proposed.

The lowest 30 feet of littoral marine deposits is overlain by fresh-water sediments containing *Lampsilis siliquoidea* and other fresh-water mollusks; the designation "*Lampsilis* Lake" is proposed. This lake probably formed when uplift near Quebec exceeded eustatic sea-level rise, and it discharged both by Quebec and the Hudson River. The permanent outlet formed in the soft rocks near Quebec.

Internally consistent C14 shell dates of the *Hiatella* phase range from 11,300 to 10,200 years B.P.; the *Mya* phase may have been Hypsithermal.

INTENSE FAULTING AT DES PLAINES, NORTHEASTERN ILLINOIS

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Intense deformation, previously considered similar to that at several so-called "cryptovolcanic" structures and commonly identified as the Des Plaines Disturbance, occurs in an area of about 20 square miles centered at Des Plaines, northeastern Illinois. Essentially flat lying, gently warped lower Paleozoic rocks surround the disturbed area in which beds ranging in age from Pennsylvanian to middle Ordovician underlie the glacial-drift cover. Maximum disturbance occurred at the City of Des Plaines where many small blocks are separated mainly by high-angle faults. Here Mississippian

and Pennsylvanian rocks have been faulted against middle Ordovician rocks, and the younger rocks are preserved as much as 50 miles north of the principal outcrop belt. The stratigraphic throw is as much as 650 feet, and the faulting occurred both before and after Pennsylvanian time.

A gravity survey of the region has disclosed a negative anomaly near Des Plaines. This negative anomaly, the normal thickness of the beds, lack of overturned blocks, and high-angle faulting of at least two ages are not readily explainable by the present theories of the origin of "cryptovolcanic" structures.

REVIEW AND EVALUATION OF STUDIES OF THE O^{18}/O^{16} RATIO IN MINERAL DEPOSITS

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Knowledge of the variations in the ratio O^{18}/O^{16} in minerals and entrapped fluids of ore deposits and their wall rocks, if coupled with thoughtful field studies, will contribute to our understanding of (1) the physical and chemical environment of ore formation; (2) the amount, kind, and source of any large volumes of oxygen-bearing fluids associated with ore genesis; (3) the scope and interrelations of supergene, hypogene, and sedimentary processes; and (4) the paragenesis of minerals in the deposits.

Variations in the isotopic composition of oxygen seem especially useful in defining the temperature of growth or of recrystallization of oxygen-bearing minerals, the degree of chemical equilibrium approached during crystallization, and the extent to which magmatic or metamorphic fluids may have been mingled with meteoric waters.

Studies of the variations of O^{18}/O^{16} in some alteration zones enveloping and genetically related to ore, if complemented with field and other laboratory studies, may prove useful as a guide to ore.

Although work done to date suggests this enormous potential value of oxygen isotope studies, the lack of follow-up of these studies seems to indicate the scarcity of skilled and interested personnel and of physical resources in research geology. Perhaps this is largely related to the fact that too many of us are interested in mineral deposits largely as a source of income rather than as fascinating phenomena to be understood.

GEOCHEMISTRY AND LINEAMENT TECTONICS

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The regmatic pattern of the earth has been concluded by some investigators to be delimited by two main trend sets, east-west and north-south for one and northwest-southeast and northeast-southwest for the other. More than 84 per cent of studied ore deposits, on a world-wide basis, fall on intersections or along these lines. The structural features of the remaining deposits have not been clearly defined.

The lineament pattern is a consequent tectonic feature inherited by all younger rocks from earlier established patterns. Outside the areas in which the lineament sets predominate very few ore deposits occur.

Geochemistry has become the proper tool to investigate and evaluate the claims made for lineament tectonics. Three broad east-west belts define the copper provinces of North America, and within these same areas most other mineralization is restricted. Topologically three less broad belts of north-south trend also define the copper provinces.

Applied geochemistry and lineament tectonics have been demonstrated to save 80 per cent of the usual expense and nearly the same percentage of time in the exploration for and evaluation of ore deposits. Tectonic features without extension to depth yield negative geochemical anomalies. Those

that penetrate deep enough to permit egress of exotic material provide positve anomalies which permit the delineation of mineralized zones and the discovery of ore deposits.

The actual merit of the combined approach of geochemistry and lineament tectonics can be established only by applying the methods in the field, a challenge to the geologists at large.

GLAUCOPHANE STABILITY AND THE GLAUCOPHANE SCHIST PROBLEM

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Glaucophane, $Na_2Mg_3Al_2Si_8O_{22}(OH)_2$, has been hydrothermally synthesized and its stability field determined. Its high-temperature stability limit ranges from 850°C. at 175 bars P_{vapor} to 868°C. at 2000 bars P_{vapor}. Excess silica lowers the amphibole high-temperature stability limit 15°C.

Experiments suggest that production of glaucophane does not require high pressure, and that in rocks of appropriate bulk composition (high Na_2O, MgO + FeO, low CaO, with respect to Al_2O_3) it should have a wide P-T stability range; moreover, hypersodic bulk compositions should promote formation of intermediate members of the glaucophane-riebeckite series. Because of the scarcity of such chemical environments, occurrences of glaucophane over a wide range of physical conditions are rare.

However, many glaucophane schists have compositions similar or nearly identical to greenschists and epidote amphibolites. Provided they represent equilibrium assemblages, such glaucophane schists must have formed under P-T conditions different from those of the greenschist and epidote amphibolite facies. Although experimental investigation indicates that the presence of glaucophane alone is insufficient to define the facies, graphical analysis of the chemical-mineralogic constitution of low-grade metamorphic rocks shows that the glaucophane schist facies should be recognized on the basis of the assemblages: (1) glaucophane + calcium-aluminum silicate (rocks of basaltic composition); (2) glaucophane + white mica (aluminous rocks); and (3) glaucophane + jadeitic pyroxene + quartz (soda-rich or water-deficient rocks). Reactions promoting formation of these assemblages from greenschists and epidote amphibolites involve volume reductions, hence the glaucophane schist facies is favored by increased pressure and/or lower temperature.

BORON ANALOGUES OF ALKALI FELDSPARS AND RELATED SILICATES

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The boron analogues of albite (reedmergnerite, $NaBSi_3O_8$), potassium feldspar ($KBSi_3O_8$), and kalsilite ($KBSiO_4$), as well as searlesite ($NaBSi_2O_6 \cdot H_2O$) and several other borosilicates, were synthesized, and their phase relations were partly determined.

Reedmergnerite, with a powder pattern identical to that of natural reedmergnerite, was obtained between 300° and 500° C. at P_{H_2O} = 2000 bars. It melts incongruently to quartz + glass under the following conditions: 862° C. dry (Morey); 567° ± 5° C., P_{H_2O} = 1000 bars; 516° ± 5° C., P_{H_2O} = 2000 bars.

At P_{H_2O} = 2000 bars the equilibrium searlesite + quartz $\rightleftarrows$ reedmergnerite + water was located at 285° ± 5° C., with searlesite + quartz the low-temperature assemblage. Searlesite was synthesized on its own composition and was found to melt to reedmergnerite + glass at 300° ± 10° C. and P_{H_2O} = 2000 bars.

Assemblages observed in the Green River formation are searlesite + analcite + chalcedony, reedmergnerite + analcite + chalcedony, and albite. These are consistent with the data presented here and those of Fyfe and others on the corresponding Na-Al minerals.

Solid solution on the albite-reedmergnerite join extends at least to $Ab_{80}Rd_{20}$. The pronounced lowering of the melting point of albite by the addition of boron may be significant in the formation of some pegmatites.

A boron analogue of potassium feldspar was prepared between 200° C. and 550° C. at P_{H_2O} = 2000 bars. It too melts incongruently to quartz + glass. The boron analogue of leucite did not appear. A boron analogue of kalsilite grows readily between 350° and 600° C. An orthorhombic feldspar, structurally similar to danburite (M. Mrose), was synthesized on the join $NaBSi_3O_8$—$KBSi_3O_8$.

NEW WURTZITE POLYTYPES FROM JOPLIN, MISSOURI

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Small, hemimorphic hexagonal crystals implanted on botryoidal zinc sulfide from the Zig Zag mine, Joplin, Missouri, have been studied by crystallographic and X-ray diffraction techniques. They are identified as a new wurtzite polytype, wurtzite-10 H. The unit-cell data are: space group, $P6_3mc$; a = 3.824 Å, c = 31.20; cell contents, 10ZnS. Comparison of diffraction-intensity data indicates that the published structure of SiC-10H (stacking sequence 3223) is different from that of wurtzite-10H. Calculation of intensities for various models shows that the stacking sequence for wurtzite-10H is 55. Crystals of wurtzite from Joplin described by A. F. Rogers (1904) were evidently wurtzite-10H. Powder-diffraction data revealed the presence of another polytype, wurtzite-8H, with a hexagonal unit cell: space group $P6_3mc$; a = 3.82 Å, c = 24.96; cell contents 8ZnS. Wurtzite-6H was also found at the Zig Zag mine. The wurtzite polytypes evidently form a homologous series (2H, 4H, 6H, 8H, 10H) resulting from growth phenomena based on screw dislocations. The crystals described here constitute the first natural occurrence of wurtzite polytypes to be described outside of the Western Pennsylvania localities where they were found by Seaman and Hamilton (Am. Mineral., v. 35, p. 43–58, 1950).

DYNAMICS OF STREAM BRAIDING AS SHOWN BY MEANS OF TIME-LAPSE PHOTOGRAPHY

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Mechanisms of channel-pattern change of a braided glacial stream are shown by motion pictures taken at 12 to 20 frames per minute. The study area lies entirely within the limits of the Emmons Glacier, Mt. Rainier, Washington, as it was mapped in 1910, and the area is at present surrounded and in part underlain by stagnant ice.

The braided pattern changes rapidly during periods of discharge of 300 to 500 cfs but adjusts toward a meandering pattern at lower discharges. Materials being deposited range in median diameter from 100 to 180 mm as determined by pebble counts.

Features produced by the rapidly changing stream include topographic noses and ponds dammed by stream deposits. Pattern changes occur when aggradation in the channel acts as a valve to divert flow from one channel to another. Bank cutting and consequent bar deposition cause lateral migration of the channel.

Rb-Sr FELDSPAR AGES IN GRANITIC ROCKS OF SUDBURY-BLIND RIVER, ONTARIO, CANADA

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Age studies of biotite previously reported from the vicinity of Sudbury show marked discrepancies between K-A and Rb-Sr values for all the rock types investigated. K-A ages range from 1400 to 2100 m.y.; Rb-Sr ages range between 1260 and 1675 m.y. As a further step in the investigation, the Rb-Sr age of potassium feldspar in granitic and rhyolitic rocks is now under study from a larger area extending west to Blind River. Biotite is available for comparative ages in only a few of these

localities; in K feldspar the Rb is too low relative to Sr for successful analysis in about half the samples collected.

Currently available Rb-Sr analyses in K feldspar from granitic rocks, starting at Blind River and approaching Sudbury, are as follows:

Locality	Age, m.y.	Geological environment
Pronto mine	2260±10%	Unconformable beneath U-bearing conglomerates
Panel Mine	2245±5%	60 mi. west of highly disturbed Sudbury eruptive
Cartier	2085±5%	25 mi. northeast of highly disturbed Sudbury eruptive
Porter Tp.	1955±5%	10 mi. west of highly disturbed Sudbury eruptive
Ministic Lake	2085±8%	10 mi. northeast of highly disturbed Sudbury eruptive
Chicago Mine	1580±5%	At west end of highly disturbed Sudbury eruptive
Murray	1455±5%	Middle of highly disturbed Sudbury eruptive

These values indicate the elapsed time since K feldspar was affected by any thermal event drastic enough to disturb its radioactive "clockwork". It may be significant that the higher values in the table are from localities increasingly distant from the highly disturbed south range of the Sudbury eruptive.

PLEISTOCENE BEACHES ALONG THE NORTH SHORE OF LAKE SUPERIOR

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Raised beaches between Duluth, Minnesota, and Marathon, Ontario, were investigated in 1958 and 1959 by means of aerial photographs and altimeter and hand-level traverses. Old shore lines occur as high as 1100 feet above sea level near Duluth, nearly 1300 feet in Cook County, Minnesota, but only 1030–1040 feet near Marathon. The Nipissing (?) shore line, which is the lowest prominent strand, rises from present water level (602 feet) not far north of Duluth to 710 feet in the Marathon area; however, east of Schreiber, Ontario, the Nipissing (?) stage is represented in many places by a succession of cobble beaches which occupy a vertical interval of 10 to 30 feet. Additional field evidence tends to support the published correlation—*i.e.*, that Lake Minong is the highest lake which occupied the entire Superior basin. The Minong beach lies about 780 feet above sea level at Thunder Cape, 990 feet at Schreiber, and 1030 feet at Marathon; furthermore, the Lake Nipigon basin appears to have been cut off from the Superior basin at the Minong stage. Unpublished surficial maps of the Pic-White Otter drainage area (Ontario) seem to negate any northward drainage from the Superior basin into Hudson Bay.

ARGON AGES OF THE GREAT ASH BED FROM THE ORDOVICIAN OF ALABAMA AND OF THE BENTONITE MARKER IN THE CHATTANOOGA SHALE FROM TENNESSEE

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The arkosic ash bed at the top of the Carters limestone of the Stones River group of Middle Ordovician age is a particularly interesting rock for age determination, for it contains abundant

coarse (~1 mm) euhedral biotite and some zircon. Its stratigraphic position is accurately known, so that it becomes an important tie point in the geologic time scale. At or near the surface the rock quickly weathers to a green clay, and the biotite usually alters to vermiculite. Underground the rock retains a grayish color and the appearance of a calcareous arkose. We have sampled this same bed in two deep mines near Bessemer, Alabama. The potassium-argon age of the biotite is 420 m.y. Another important marker, a 1-inch bentonite layer in the upper part of the Dowelltown member of the Chattanooga shale of Late Devonian age, also contains biotite and is protected from weathering by impervious overlying strata. Collected from a deep new road cut near the Sligo bridge, Smithville, Tennessee, biotite from this bentonite layer gives a potassium-argon age of 340 m.y. Surprisingly, these K-Ar ages are not significantly greater than the ages assigned to the Middle Ordovician (about 400 m.y.) and the Late Devonian (about 310 m.y.) on the Holmes-Marble time scale.

THERMAL TRANSFORMATION AND PROPERTIES OF CRYPTOMELANE

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An unusual occurrence of needles of cryptomelane in cavities in a manganese ore from western Australia is described. X-ray-diffraction data for the acicular crystals are indexed in terms of a body-centered tetragonal unit cell although optical examination of the crystals indicates a pseudotetragonal cell. The X-ray-powder data are more detailed than those previously reported for cryptomelane. Fiber patterns obtained from the crystals, heat-treated in air at various temperatures and times, establish the following thermal transformations and relative orientations parallel to the [001] axis of cryptomelane.

$$\underset{\text{cryptomelane}}{[001]} \xrightarrow{\Delta} \underset{\text{bixbyite}}{\overset{[110]}{[100]}} \xrightarrow{\Delta} \underset{\text{hausmannite}}{[100]} \xrightarrow{\Delta} \underset{\text{spinel}}{[110]}$$

A new transformation product of cryptomelane indexed in terms of a spinel structure, $a_0 = 8.42$ Å' is reported.

A correlation of thermogravimetric data with phase determinations shows that cryptomelane does not transform completely to bixbyite before the formation of hausmannite begins. At a heating rate of 6°C. per minute, the critical temperature for formation of bixbyite from the acicular crystals of cryptomelane is approximately 600°C., for the hausmannite approximately 825°C., and for the spinel approximately 1050°C.

FAULTING IN ENGINEERING STRUCTURES LOCATED IN THE ALLEGHENY PLATEAU

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Eleven of 18 major flood-control and navigation structures, built or designed by the U. S. Army Corps of Engineers in the Pittsburgh District since 1934, have had faults in their bedrock foundations. Since siting is based chiefly on hydraulic or hydrologic suitability and economics, structures have to be adapted to existing conditions. Faults substantially increase structure-foundation costs because remedial measures, such as increased excavation and grouting, are usually necessary. Also, delimiting the fault can increase exploration costs 100 per cent.

Detection of bedrock faulting in the early structures was difficult, because core recovery was poor in the softer sediments of the cyclically deposited Pennsylvanian system; also, there were no adequate criteria for recognizing faults in cores from these rocks and no history of faulting in the areas.

Subsequently, improved drilling equipment, chiefly series M and L core barrels, development of the borehole camera, and a better supervision of drilling gave a more detailed geologic picture; thus, better criteria for recognizing faults in foundations have been developed.

All faults have been found in river valleys, and most occur as low-angle thrusts with a displacement of 2 feet or less. Soft gouge or breccia zones are found up to 18 inches thick but are seldom recovered by coring if more than 1 inch thick.

There is no general orientation of the strike of the faults and no apparent relationship to regional structures.

PETROLOGY OF THE KITTANNING FORMATION NEAR BROOKVILLE, PENNSYLVANIA

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The Kittanning formation near Brookville, Pennsylvania, consists of about 100 feet of middle Allegheny strata exposed on the northeast flank of the Pittsburgh-Huntington synclinorium. The formation is mainly detrital—sandstone, siltstone, and claystone—but contains minor amounts of coal, ironstone, and limestone. It is composed of about 70 per cent micas and clays occurring either as loose flakes of muscovite, chlorite, biotite, sericite, illite, and kaolinite or as aggregates ranging from muscovite-chlorite schist to poorly consolidated clay "galls". The remaining constituents are 25 per cent quartz and 5 per cent feldspar, carbonates, and other minerals. The mean of the Kittanning grain-size distribution is slightly less than 5 phi (coarse silt), and the standard deviation is greater than 2 phi units. The colors of most rocks are neutral shades ranging from light gray to very dark gray. Small-scale stratification is complex but can be reduced to two major categories—layered or bedded and nonbedded. The fauna is principally brachiopod and molluscan. The flora is dominated by familiar Pennsylvanian lycopsid remains and fernlike foliage.

Megascopically distinguishable lithologic types within the Kittanning can be described on the basis of quartz content and color relative to mean grain size, and by differences in stratification and fossil content. These lithologic types, each presumably reflecting specific circumstances of deposition, are restricted in stratigraphic and geographic distribution.

Interpretation of petrographic and stratigraphic evidence suggests a Kittanning history consisting of two episodes of marine or brackish transgression interrupted by a time of fluvial and lacustrine deposition.

PERMIAN HEXACTINELLID SPONGE FAUNA FROM TEXAS

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The basin facies of the West Texas Permian has yielded the first known Permian hexactinellids, the most diverse such fauna between the Devonian of New York and the Jurassic of Germany. Only *Stromatidium typicale* Girty has been described previously. Three new superfamilies, 7 families (5 new), 10 genera (9 new) and 15 species (14 new) are recognized. The fauna includes relatives of the Ordovician *Teganium* and *Brachiospongia* and of the mid-Paleozoic dictyosponges, as well as a new group.

Most abundant are relatives of dictyosponges and *Brachiospongia*. These represent two major lineages originating at least as far back as the Ordovician. The former lineage, developed from Cambrian protospongiids, has uniform, regularly arranged spicules. The latter has specialized dermal spicules over an irregular interior skeleton. In both lineages, Permian forms show an increased thickness and rigidity of the body wall. The dictyosponge line attained this condition by expansion of an inner layer of spicule bundles in one case and of an outer layer of hexacts in another. The second type ap-

proaches the Triassic and later dictyonine structure. Permian relatives of *Brachiospongia*, on the other hand, exhibit great enlargement and elaboration of the dermal spicules, which may fuse into a rigid outer layer, quite different from the similarly rigid dictyonine skeleton.

None of the Permian families, except possibly one related to *Brachiospongia*, seems to have survived the Paleozoic. Permian dictyosponges may have given rise to later dictyonines, and the new Permian group may have been ancestral to the euplectellids.

STRATIGRAPHIC DISTRIBUTION OF SPONGES IN THE UPPER PALEOZOIC OF TEXAS

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Major faunal breaks permit recognition of four broad zones: (1) Desmoinesian to Virgilian, (2) Wolfcampian (including the *Uddenites* member of the Gaptank formation), (3) Leonardian (including Word limestone one), and (4) Guadalupian. The most pronounced break is at the base of the Leonardian, marked by the first appearance of pharetronids and *Guadalupia*. Within the first zone, faunal changes at the standard series boundaries can be recognized, as well as two within the Missourian. A break within the Leonardian zone, at the level of the top of the Hess member, is marked by the disappearance of both *Heliospongia* and of a new hexactinellid genus. The three formations of the Guadalupian (Brushy Canyon, Cherry Canyon, Bell Canyon) and their equivalents can also be identified.

Zone 1 is a uniform shelf environment dominated by calcisponges. Sponge reefs first appear in zone 2 and contain a fauna related to that of the preceding and contemporaneous shelf association. A new calcisponge element appears in both reef and shelf deposits of zone 3 alongside many of the older types. A deeper-water basin environment, populated by hexactinellids and lithistids, is also present in this zone. Many of the lithistids are abundant in the shelf deposits as well. In zone 4, sponge-dominated barrier reefs, as well as patch reef and shelf deposits, consist largely of the new calcisponge element introduced in the preceding zone. The basin environment persists with an apparently impoverished fauna.

BASAL CAMBRIAN STRATA IN THE NORTHERN BIG HORN MOUNTAINS, WYOMING

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Recent erosion in the Northern Big Horn Mountains has exposed an erosion surface on Precambrian granite. Precambrian knobs on this surface range from 200 to 1100 feet in length and have a maximum relief of 82 feet. Several of these knobs can be seen in the area 1 mile east of Burgess Junction and also immediately west of Little Baldy Mountain. The granite immediately below the basal Cambrian sandstone exhibits an unweathered surface in most areas. Stained and weathered pockets of granite up to 2 feet thick can be found in protected hollows.

The basal arkosic sandstones are Middle (?) Cambrian. At Medicine Mountain the lower 3 feet of sandstone contains ventifacts of iron-stained quartz derived from quartz veins in the granite. The ventifacts range in size from half an inch to 6 inches and are characterized by sharp edges. The preservation of the angularity in these features indicates a relatively rapid encroachment of the Cambrian sea. Wave erosion was intense enough to remove most of the weathered granite but not sufficient to plane off the knobs.

Conglomerates are developed around the bases of some of the knobs. Granite, diabase, and a silicified zone in one knob correspond with the rock types found in the conglomerate around the knob. Subrounded boulders in the conglomerate were produced by weathering rather than transportation. The conglomerate contains abundant oboloid brachiopods and a few trilobites.

PERMO-TRIASSIC STRATIGRAPHY OF THE EASTERN BIG HORN MOUNTAINS, WYOMING

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Surface and subsurface studies from Alcova northward to the Montana line indicate that the Goose Egg formation rests upon an eroded surface of Tensleep sandstone characterized by conglomerate, chert pebbles, and fissure fillings. The Goose Egg formation thins northward from its type locality. The Opeche shale and Minnekahta limestone members persist at least to the Montana line. Shales and evaporites resembling those below the Ervay limestone member extend to the vicinity of Dayton. The Chugwater formation ranges in thickness from approximately 800 to 450 feet. The Alcova limestone member can be traced as far north as the town of Big Horn. The Red Peak and Crow Mountain members can be distinguished where the Alcova is present, but there appears to be no evidence for the recognition of the Popo Agie member in the area. The Gypsum Spring formation consists of dark-red shales grading upward into, gray, green, and purple shales and subordinate interbedded limestones. The Gypsum Spring formation is absent south of Mayoworth and thickens to the north. The overlying basal oölitic limestone of the Sundance formation is a prominent marker bed throughout the area.

PROBLEMS IN THE ESTIMATION OF ABUNDANCES OF ELEMENTS IN THE EARTH'S CRUST

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Estimates of the abundances of elements require that analyses made in many different laboratories the world over by many different methods on a wide variety of rocks be averaged. The possible errors due to faulty analyses have been discussed by Fleischer (1955) and Ahrens (1957); interlaboratory comparisons on the two rocks, granite G-1 and diabase W-1, have led to considerable improvement in this respect.

A second major difficulty is that the estimates of abundance require assumptions as to the relative amounts in the crust of the various rock types, and especially of igneous rocks. Most such assumptions are based on the estimates of Vogt (1931) and Daly (1933) or modifications of these, such as Engelhardt's (1936). For elements concentrated in mafic rocks, such as nickel and chromium, and for elements concentrated in silicic rocks, such as barium and rubidium, the data available on specific rock types are probably better than the estimates of the relative amounts of the rock types. There is therefore an urgent need for region-by-region estimates of the relative abundance of rock types. Until these are available, averages for specific rock types are probably more useful than over-all averages for the crust.

In averaging, care must be taken not to lose sight of regional variations. For some elements, notably uranium and zirconium, there appears to be marked regional variation in the course of concentration of these elements during magmatic differentiation.

MINERALIZATION OF A PORTION OF THE PORPHYRY COPPER DEPOSIT NEAR ELY, NEVADA

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The geology of the Liberty open-pit copper mine was mapped in detail. The original textures of ore-bearing porphyritic rocks were similar to one another but differed markedly in groundmass texture

from nonsulfide-bearing porphyritic rocks in the district. In one area of the pit igneous material appears to have been injected simultaneously with economic mineralization and alteration. A sericite alteration of plagioclase in one rock preceded the intrusion of a second rock in which the plagioclase is altered to montmorillonite. The primary copper content of the first rock is several tenths of a per cent higher than that of the second rock. Most chalcopyrite is distributed as grains in the groundmass with no trace of alignment along previously existing cracks. Other chalcopyrite grains are found along cracks "healed" by quartz and K feldspar. Small amounts of chalcopyrite are along "unhealed" cracks.

In another portion of the pit a large porphyry body exhibits a concentric zonal alteration pattern related to fissures and pyrite-bearing veins. The outermost zone contains kaolinite after plagioclase and black biotite after hornblende. An intermediate zone contains recrystallized brown biotite (magnesium-rich eastonite) with sericite or sericite plus K feldspar replacing only plagioclase. In the innermost zone the only silicates are quartz and a magnesium-rich dioctahedral mica.

GEOLOGY OF FURNAS DAM, MINAS GERAIS, BRAZIL

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This large hydroelectric project, now under construction, is located on the Rio Grande in the southwestern part of the state of Minas Gerais, Brazil, will have an installed capacity of 1,200,000 KVA, and will be the largest reservoir and hydroelectric project in Brazil. The earth and rock-fill dam will be 112 m high and will be founded on Precambrian quartzites. Deep weathering of schists in the right abutment influenced the design of the dam and the choice of an earth and rock-fill dam. A large fault with diabase intruded along it exists in the river channel, but the foundation problems associated with the fault are not critical. Local quartzite will be used for aggregate and rock fill.

KEWEENAWAN DIASTROPHIC CYCLE ON THE EAST SHORE OF LAKE SUPERIOR

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Rock assemblages of a Keweenawan mobile belt were mapped near Batchawana, Ontario, to determine the diastrophic history of the area. Steeply dipping to vertical lavas, tuffs, cherts, iron formations, shales, argillaceous limestones, and dolomites strike east-west and occur on the east side of the Lake Superior border fault. Diabase intrudes the lavas and sediments. Conglomerates, red beds, and lava flows occur on the west side of the fault. They strike north to northwest and dip gently west. Commercial-grade copper deposits are confined to a set of radial faults on the west side of the border fault.

Field and petrographic evidence plus dates obtained by others indicate the following events: The basement is a granite about 2.3 billion years old. The eugeosynclinal belt of steeply dipping to vertical lavas and sediments was laid down 1.35 billion years ago and intruded by diabase 1.2 billion years ago. This belt, infolded into the granite about 1.2 billion years ago, extended into the area now covered by Lake Superior before it was displaced by the Lake Superior border fault. On the west side of the border fault, lava flows, fanglomerates, and red beds were deposited about 1.1 billion years ago. A postorogenic diabase plug intruded the rocks on the east side of the border fault. The copper-bearing radial faults may reflect the presence of a diabase plug at depth.

Such a Keweenawan orogenic cycle has not been previously recorded.

S^{32}/S^{34} ISOTOPIC-ABUNDANCE RATIOS AND GENESIS OF SULFIDE ORE BODIES AT SUMMITVILLE AND ELLENVILLE, NEW YORK

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Laboratory and field investigation of the sulfide ore body at Summitville and of remaining accessible exposures of the ore body at Ellenville, New York, reveal basic similarities in the chief minerals present, paragenesis, and structural control, although differences in auxiliary minerals and zoning were noted. Sphalerite geothermometry indicates that the upper part of the Summitville ore body formed at approximately 325° ± 25°C.; pressure was not greater than 10,000 atmospheres. Ore-forming fluids rich in zinc, iron, lead, and copper and carrying traces of gold, silver, cadmium, and manganese were deposited at the Summitville locality during a single period of sulfide metallization, preceded and accompanied by tectonic activity; they are interpreted as mesothermal hypogene deposits.

Supergene sulfide deposition and development of an oxidized zone at Summitville did not advance beyond an initial stage. Uniformly low S^{32}/S^{34} abundance ratios between 21.72 and 21.74, a comparatively narrow spread $<\pm 0.2$ per cent, are below those previously reported for sulfides of undoubted biogenic and sedimentary origin; the narrow range may support geothermometric evidence for a hypogene origin of the ore body. S^{32}/S^{34} ratios may distinguish exsolved chalcopyrite and sphalerite (21.72) here from a later replacement generation of chalcopyrite (21.66), and vein pyrite (21.55) from other pyrite (21.70).

INTERBASIN RIVER SYSTEMS SUPERIMPOSED ON THE MAJOR PENNSYLVANIAN COAL BASINS*

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Southwestward-trending cross-bedded sandstones in channels interpreted as segments of former river systems, and the absence of evaporites and major deltaic deposits, suggest that interbasin river systems were repeatedly superimposed on the major Pennsylvanian coal basins. These Pennsylvanian rivers emptied into an ocean near the present Gulf of Mexico.

The Michigan coal basin possibly drained southwestward into the Eastern Interior coal basin through a structural sag in northwestern Indiana, and part of the Appalachian coal basin probably drained westward into the Eastern Interior coal basin through the sag between the Nashville dome and the Cincinnati arch. The Eastern Interior coal basin probably was drained by a principal river flowing south-southwestward through the Mississippi Embayment area. This river may have been joined in northern Louisiana by another river flowing west-southwestward from the Warrior Basin. The Western Interior coal basin possibly was drained either by a river flowing southeastward into Arkansas, where it joined the principal river in the Mississippi Embayment area, or by a river through the southeastward-trending seaway postulated by H. J. Morgan in 1952 between the Ouachita Mountains and the Red River uplift.

Tectonic and paleogeographic maps indicate that the lower courses of the one or more principal rivers must have been either southwestward into Mexico parallel to the mountains of Llanoria or southward through structural valleys in these mountains.

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INTERPRETATION OF GLOBALLY DISTRIBUTED ANASTOMOSING CHANNEL DRAINAGES

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Throughout the world large-scale anastomosing channel drainages occur where recently or formerly accentuated runoff traverses terrain developed by severe arid aggradation-planation processes. Drainage systems carrying perennial runoff near, into, or through deserts provide optimum study conditions. Currently, most perennial anastomosing channel patterns and genetically related features are developed along arid-humid geographic transition zones downslope from headwaters but prior to attainment of subarid or arid regimens—often well within humid regions. Anastomosing networks on or near humid-area land-elevation maxima are rare. Present network dispositions indicate that relatively high elevation areas act as humid climate nuclei for irregular areal adjustments of humid and arid regimens by peripheral expansions and contractions. Nuclei within some currently humid areas appear quasipermanent. Perennial inundation of anastomosing channel networks axiomatically establishes recently accentuated headwaters humidity.

Geographic extent of most recent climate regimen adjustments is expressed by distance from ad-humid end of perennial anastomosing network to present arid regimen boundary. Maximum indicated recent humid regimen peripheral expansions coupled with precipitation and runoff augmentation include: North America, 800–1000 miles; South America, 600–700 miles; Africa, 500–600 miles; Australia, 200–300 miles; Asia, 200–?500 miles. Geographically removed and less well documented, locally correlative arid encroachments into the same humid regions range from 100 to 400 miles. The greatest recent areal expansions of humid regimens are in eastern portions of continents, and greatest intensities are equatorial.

RECENT CLIMATE CHANGE PATTERNS—A MODE OF CONTROL

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Recent moisture increases and humid regimen areal expansions in eastern portions of the Americas, Africa, Australia, and Asia are indicated by study of anastomosing channel-drainage distributions and associated climate indices. Generally correlative humidity accentuations along western continental borders are subordinate to adjacent aridity intensifications in the Sahara, Kalahari, Australia, Peru, and probably California and Sonora deserts. Areas of intensified aridity closely reflect adjacent cold boreal-origin marine surface currents, whereas greatest humidity increases are adjacent to warm currents of equatorial origin.

South American studies demonstrate complex east-west climate alternation associated with Antarctic glaciation. Cooling seas initially intensify western aridity and diminish eastern low-level moisture coincident with east Andes alpine glaciation. General eastern aridity and western alpine glacial-humidity follows, only to revert to the initial conditions during glacial recession as a prelude to present relationships. Climate-change patterns on other continents indicate similar complexity.

Warm currents to the west of continents and cold currents to the east during Antarctic glacial maxima are required to explain the pattern of climate changes recorded. Elimination of the circum-Antarctic Current as prime mover of cold-derived surface currents during glacial maxima is postulated as the cause. Glacial blocking of 500-mile-wide Drake Strait, constriction of other southern seaways by ice, and sea-ice exclusion of West Wind-water frictional drive coupled with southern ocean low-pressure developments next to an accentuated polar high would reverse Southern Hemisphere surface currents and modify others to the north.

SOLUBILITY OF CARBONATES IN SEA WATER; CONTROL BY CARBONATE COMPLEXES

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When NaCl is added to water containing dissolved carbonate, the sodium ion interacts with the carbonate ion to form $(NaCO_3)^-$; $\frac{{}^aNa^+ {}^aCO_3^{--}}{{}^aNaCO_3^-} = 5 \times 10^{-2}$. Similarly, addition of $MgCl_2$ causes the formation of molecular dissolved $(MgCO_3)^0$; $\frac{{}^aMg^{++} {}^aCO_3^{--}}{{}^aMgCO_3^0} = 4 \times 10^{-4}$. Experiments with bicarbonate solutions also indicate that there is weak association between Na^+ and HCO_3^-, and between Mg^{++} and HCO_3^-. No satisfactory constants were obtained.

Complexing of the carbonate ion owing to formation of $(NaCO_3)^-$ and $(MgCO_3)^0$ accounts for the anomalously high concentration of carbonate in sea water. According to our data, the ion product $[Ca^{++}][CO_3^{--}] = K'$ would be only about 40 per cent of that observed if sea water contained no magnesium.

The observed value of the second dissociation constant of carbonic acid in sea water K_2' is duplicated by calculations that make use of the dissociation constants for $(NaCO_3)^-$ and $(MgCO_3)^0$.

CRYSTAL STRUCTURE OF CUMMINGTONITE AND Mg-Fe ORDERING IN FERROMAGNESIAN AMPHIBOLES

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The crystal structure of a cummingtonite, with about 62 per cent of the Mg component (cell dimensions $a = 9.51_4$ Å; $b = 18.18_8$ Å; $c = 5.33_3$ Å; $\beta = 101° 55'$; space group C 2/m) has been refined by the least-square method using three-dimensional intensity data and the parameters of grunerite as input. The structure of cummingtonite is the same as that of tremolite, except that the silicate chains are slightly modified to take care of the difference in the ionic sizes of (Mg,Fe) and Ca. The silicate double chains are slightly concave away from the metal atoms. It is found that M_4 position (corresponding to Ca position in tremolite) is principally occupied by Fe^{2+}, and M_2 position principally by Mg^{2+}, while M_1 and M_3 positions are occupied by the rest of the Mg,Fe in a random manner.

THERMAL REACTIONS OF HYDRATED SODIUM TETRABORATES

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The thermal reactions of the hydrated sodium tetraborates, borax—$Na_2B_4O_7 \cdot 10H_2O$, tincalconite—$Na_2B_4O_7 \cdot 5H_2O$, and kernite—$Na_2B_4O_7 \cdot 4H_2O$ have been investigated by means of DTA, the thermal-increment diffractometer, X-ray diffraction, and infrared spectrophotometry. Borax undergoes three endothermic reactions at 90°, 130°, and 155°C. (peak temperatures); tincalconite undergoes one endothermic reaction at 155°C., and kernite undergoes one endothermic reaction at 180°C.

The first endothermic reaction of borax (90°) yields a mixture of tincalconite and borax. Grain size does not appear to be a critical factor. The second reaction (130°) is the conversion of the remaining borax to tincalconite. The final reaction (155°) is the breakdown of tincalconite to a glass. The endothermic reaction of tincalconite is identical to the final reaction of borax—*i.e.*, tincalconite to glass. The kernite reaction is also a decomposition to a glass. The identification of crystallographic

reactions not delineated by standard DTA and X-ray methods is of special interest. Data from the thermal-increment diffractometer indicate that tincalconite becomes amorphous at 130°–140°C. The identity of the amorphous material as a form of tincalconite has been established by infrared spectroscopy. Thus, the endothermic reaction at 155°C. really involves the decomposition of the amorphous tincalconite to a glass. Similarly, kernite changes to another crystalline phase at about 160°C. and then decomposes to a glass at a slightly higher temperature. These conversions are apparently caused by the complex nature of borate structures which become disordered at a temperature below the decomposition point.

SOLID DIFFUSION AND VOLATILITY OF SULFIDES—SOME EXPERIMENTAL RESULTS

J. E. Gill

Experiments carried out by J. F. MacDougall, B. K. Meikle, and J. V. Guy Bray under the direction of J. E. Gill and V. A. Saull prove that some sulfides generally regarded as nonvolatile are slightly volatile under low sulfur-vapor pressures. Chalcocite heated in nitrogen and sulfur vapor showed appreciable volatile transfer at 675°C. in the presence of excess sulfur. Pyrite in a similar environment was transferred at 550°C. In experiments with no excess sulfur, no transfer occurred.

Some volatile transfer of cobalt sulfide was effected. Other sulfides tested gave no positive evidence of volatilization.

Solid diffusion was evident in many experiments, and this, rather than volatilization, is thought to have been the main process producing crystals on the surfaces of test specimens, veinlets of sulfides along fractures in mineral grains and rock fragments, and replacement of one sulfide by another. Textures produced resemble some in natural ores commonly attributed to replacement through the agency of aqueous solutions.

Silicates and carbonates heated in a nitrogen atmosphere with copper sulfides at 550°C. and 825°C. gave no evidence of replacement, although some may have occurred in chlorite.

PRECAMBRIAN GEOCHRONOLOGY OF MINNESOTA AND ADJACENT AREAS

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A classification of the Precambrian rocks of Minnesota and adjacent areas based on A^{40}/K^{40} age determinations on 150 samples, 30 of which have been dated by the Sr^{87}/Rb^{87} method, is presented. A three-fold division of the Precambrian is retained, but major revisions are made. Early Precambrian time ended in a major orogeny or revolution (Algoman) at approximately 2.5 b.y., and Middle Precambrian in a major orogeny (Penokean) at approximately 1.7 b.y.

Inclusion of the Knife Lake and Seine sediments in the Early Precambrian relegates the Laurentian to a minor orogeny. This interpretation makes it unnecessary to postulate a long interval of lost time between the Laurentian and Algoman granite intrusions. The duration of Early Precambrian time, however, is unknown; micas from pre-Algoman rocks all give an Algoman age.

Middle Precambrian sediments derived from the Algoman mountains are poorly represented in Minnesota. The Animikie group and similar rocks in Wisconsin and Michigan were involved in the Penokean orogeny. An early phase is represented by the tonalites (1.7–1.8 b.y.) of central Minnesota. Late-stage Penokean granites in Minnesota, Wisconsin, and Michigan are dated at 1.6–1.7 b.y.

Major events of Late Precambrian time include deposition and folding (1.2 b.y.) of the Sioux formation, accumulation of the Keweenawan lavas and intrusion (1.0 b.y.) of the Duluth gabbro and related rocks, and deposition of the Fond du Lac and Hinckley sandstones.

Dating by radioactivity is a major breakthrough; its geologic exploitation requires a vigorous renewal of field studies.

SUBSOLIDUS RELATIONS IN THE SYSTEM $CaCO_3$—$MgCO_3$—$MnCO_3$

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The system $CaCO_3$—$MgCO_3$—$MnCO_3$ was investigated at 10 kilobars total pressure, at temperatures of 500°, 600°, 700°, and 800°C. Three two-phase areas and one three-phase triangle are observed, and an additional two-phase area is inferred. At 500°C. there are two single-phase regions, which enlarge and merge at higher temperatures. At 800°C. the three-phase triangle and its adjacent Mn-rich two-phase areas occupy only a very limited portion of the diagram, and the principal two-phase regions extend into the system from the $CaCO_3$—$MgCO_3$ binary immiscibility gaps.

At 500° and 600°C. the $CaMg(CO_3)_2$—$CaMn(CO_3)_2$ join is encroached upon by the two-phase region extending from the Ca-rich portion of the system, but at higher temperatures a single-phase region extends all along the join, which becomes binary in nature. The formation of compounds having dolomite-type structures, which occurs along part of this join and in adjacent regions of the ternary system, depends upon temperature as well as upon relative proportions of the three cations.

DOLOMITE FORMATION IN LAKE BONNEVILLE, UTAH

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A thin bed of nearly pure, fossil-free, unconsolidated dolomite occurs about a foot below the surface of the Great Salt Lake Desert west of Knolls, Utah. A C^{14} date of 11,000 years correlates with the onset of a drier climate and the desiccation of Lake Bonneville to the present Great Salt Lake. A saline lake was left isolated from Great Salt Lake, and in its shallower waters the dolomite was formed.

Shoreward the dolomite zone is represented in one core by a mixture of aragonite and a magnesite-like material. The latter mineral has an enlarged unit cell which is believed to result from a hitherto undescribed type of hydration.

Chemical-enrichment techniques have been utilized in obtaining minor-element abundance data or this unusually pure carbonate sediment.

UPPER CRETACEOUS FORAMINIFERA FROM STANFORD UNIVERSITY CAMPUS, CALIFORNIA

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An upper Cretaceous siltstone along the east bank of San Francisquito Creek beneath Willow Road Bridge, on Stanford University Campus, Santa Clara County, has yielded a large and diversified foraminiferal assemblage that appears to be of Campanian age. This faunule is correlative—among others in California—with several from the upper part of the Panoche group (Uhalde shale) of Fresno County, and some from the Tracian and Weldonian stages. It is also correlative with faunas from Taylor strata of the Gulf Coast and probably with assemblages from the Upper Senonian of northwestern Europe.

The 120 species, some not previously reported from California, consist mainly of calcareous perforate and arenaceous forms. The calcareous species outnumber the arenaceous ones, but the arenaceous foraminifers have more individuals. Both bottom-dwelling and open-sea genera are present,

with the benthonic group more abundant. Dominant arenaceous species are *Haplophragmoides* sp., *Marssonella trochus*, *Plectina watersi*, and *Silicosigmoilina californica*. Coiled and rectilinear lagenids form the principal constituents among the calcareous species, with rotaliids next in abundance; anomalinids, buliminids, ellipsobuliminids, globotruncanids, polymorphinids, and others are less common or rare.

Important stratigraphic markers include *Bolivina incrassata*, *Bolivinitella eleyi*, *Bolivinoides delicatula*, *Globotruncana arca*, *G. elevata stuartiformis*, *G. fornicata*, *Neoflabellina numismalis*, and *Reussella szajnochae californica*. Associated with the foraminifers are some Campanian cephalopods (*Cymatoceras suciense* and *Baculites inornatus*).

Comparison of the Stanford faunule with analogous Recent foraminiferal genera suggests that the Cretaceous siltstone is a neritic deposit laid down in temperate waters.

NAPPE STRUCTURES IN PENNSYLVANIA

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Recent detailed studies in the Berks and Lebanon counties area of the Great Valley have indicated large-scale recumbent folds, or nappes, in the carbonate rocks. There are also indications of the presence of similar structures outside the area of detailed mapping. The area of recumbent folding has a strike length of at least 20 miles. The nappe is at least 4 miles wide and may be much wider, as the axis and root have not been definitely located. The structures are therefore on an Alpine scale.

The relation of the nappes to the crystalline basement is not yet completely clear. Where the nappes are best developed the basement is hidden by Triassic structures and deposits. At the east end of the area of detailed mapping, crystalline rocks are locally thrust over the younger carbonates. Here the basement apparently rises steeply on a series of moderate- to high-angle thrusts. It is also believed that a similar situation exists at South Mountain in Cumberland County, Pennsylvania.

GEOCHEMICAL IMPLICATIONS OF LUNAR DEGASSING

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The effect of lesser gravity on a possible lunar defluidizing process would be to nucleate bubbles at greater depth in a magma column. This may account for a more explosive type of volcanism on the moon accompanied by a greater degree of subsidence which would tend to form calderas of great dimension rather than volcanoes. It is conceivable that such defluidization and accompanying volcanism could produce five major results: (1) Extensive production of silicic extrusives including welded tuffs in nonmare areas, and subsequent evolution of mafic extrusives as maria. (2) Formation of calderas in and along volcano-tectonic zones of collapse and at fracture intersections. (3) Formation of thick volcanic dust in nonmare areas and possibly just a thin spallation in mare areas. However, local accumulation of dust in mare areas is accepted in view of post-mare development of craters in maria. (4) Appreciable concentrations of compounds, particularly of Cl, Br, S, I, and F, and to a lesser extent of Cd, As, Hg, Sb, Zn, and Pb in nonmare areas relative to the average terrestrial sedimentary rock. Most of these elements have high neutron capture cross sections; many form soluble compounds enriched in ocean water. (5) Concentration of these compounds as minerals formed in environments low or lacking in oxygen and under partial vacuum. These minerals might correspond to closed-tube sublimates obtained in determinative mineralogical techniques. Persistence of low vapor pressure "closed-tube" sublimates on the lunar surface is possible.

SAMPLING PEBBLES OF "QUARTZITE" FROM GRAVEL AT MONTOURSVILLE, PENNSYLVANIA

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White "quartzite" pebbles were sampled from a gravel pit at Montoursville, Pennsylvania, by 15 operators using three different sampling arrangements: (1) channel, (2) spot, (3) stratified. The long (a), intermediate (b) and short (c) axes were measured with the following results:

Summary Statistics

Sampling Arrangement	Pebble Axis	$\bar{X}_\phi$	s_ϕ	$\sqrt{\beta_1}$	β_2	n
1	a	−5.265	0.750	0.232*	2.890	324
	b	−4.853	0.761	0.136	2.926	
	c	−4.276	0.803	−0.192	3.024	
2	a	−5.705	0.790	0.000	2.467**	300
	b	−5.301	0.782	−0.124	2.614*	
	c	−4.719	0.749	−0.076	2.564*	
3	a	−4.867	0.818	−0.071	3.478*	336
	b	−4.488	0.806	−0.256*	3.531*	
	c	−3.981	0.836	−0.219*	3.440	

Assuming the channel samples approximate random samples from a phi-normal population then variances are not significantly different, whereas means are. Furthermore, the β statistics and significant mean differences indicate that sampling instability is inconsistent from one sampling arrangement to another, and even the channel samples exhibit nonrandomness.

Three conclusions need emphasis:

(1) An organized attack on the sampling problem is urgently necessary if quantitative analysis of rocks is to achieve stable estimates of petrographic parameters.

(2) By imposing different sampling arrangements on the same population it is possible to determine the internal heterogeneity of arrangement of the elements in the population. Such a sampling study becomes an objective procedure for characterizing texture (microscopic scale) and structure (field scale) of rocks.

(3) Only when the internal arrangement of variability is known can a random sample be defined and stable estimates obtained.

MARTIC LINE IN PENNSYLVANIA—AN AEROMAGNETIC INTERPRETATION

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Contoured aeromagnetic maps which cover the entire length of the Martic line in Pennsylvania, from Morrisville on the Delaware River to Littlestown on the Maryland State line, have been prepared by the U. S. Geological Survey.

Areas of similar magnetic pattern within the region underlain by Wissahickon schist form belts

essentially parallel to the Martic line and to regional topographic trends. These magnetic units are probably related to stratigraphic units within the Wissahickon schist. No magnetic features are seen which contradict the hypothesis that the Wissahickon schist lies in normal stratigraphic sequence upon the Conestoga limestone.

On the north side of the Martic line magnetic anomalies occur above magnetite-rich schists within the upper portion of the Antietam schist. These schists are associated with crests of anticlines and are thought to be the metamorphosed equivalent of the iron carbonate and pyrite-rich beds characteristic elsewhere of the topmost layers of the Antietam. Depth determinations on a magnetic anomaly on the Mine Ridge anticline at Quarryville indicate that the magnetic rocks causing the anomaly plunge gently southwest under the Martic line and extend beneath the Wissahickon schist a horizontal distance of more than a mile. This confirms previous structural studies that indicated that the Wissahickon schist occurs as a relatively thin and flat-lying sheet immediately west of Quarryville.

METASOMATIC VEINS IN THE BIWABIK IRON FORMATION, MINNESOTA

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Coarse-grained pegmatitelike veins, ranging in composition from granitic to lamprophyric, are found in the Biwabik iron formation of the Eastern Mesabi district, Minnesota.

In addition to albite and quartz, the calcium-iron amphibole ferroactinolite (approx. 65 mole per cent ferrotremolite) is a characteristic mineral of the veins. Calcite, plagioclase, green biotite (now largely chlorite), apatite, magnetite, pyrite, and chalcopyrite also occur widely in accessory amounts. Trace amounts of loellingite, molybdenite, muscovite, andradite, ferrohypersthene, and cummingtonite are locally found. Minor amounts of stilpnomelane, usually retrograde after ferroactinolite, are almost invariably present.

Where the veins contain abundant feldspars, the adjacent iron formation has been partially metasomatized and now contains numerous small pegmatoid pods and veinlets, especially rich in alkali feldspars. Where the veins are calcium rich, because of their high calcite and ferroactinolite content, the adjacent iron formation is commonly appreciably metasomatized. There much of the iron formation is normally reconstituted in large part to hedenbergite, within a recrystallized matrix of previously existing quartz and magnetite. In many places, large porphyroblasts of ferrohypersthene form near the veins. Both pyroxenes are always, at least partially, replaced by ferroactinolite, actinolite, and cummingtonite, all seemingly of retrograde origin. Brown and green biotite are also important metasomes. Pyrite, pyrrhotite, chalcopyrite, calcite, and rarely loellingite are intimately associated with the metasomatic hedenbergite found in the iron formation, especially where these minerals are also found in the pegmatitic vein.

HOST ROCK AS A SOURCE OF IRON, AUSABLE FORKS MAGNETITE DISTRICT, NEW YORK

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Replacement magnetite deposits in Precambrian gneisses and skarn near Ausable Forks, New York, formed by regional metamorphism and metasomatism. Material from the host rock moved to strongly disturbed, low-pressure zones and was localized by structural features. Eight square miles was mapped on a scale of 1 inch to 880 feet, and two deposits on a scale of an inch to 200 feet. Geologic interpretations are based on field studies, 320 modal analyses, more than 500 refractive-index determinations, 22 fluorescent X-ray analyses, and 10 spectrographic analyses of minerals and rocks.

Magnetite in the gneiss drops from 4 per cent at distances greater than 500 feet on either side of

the ore zones to 0 per cent adjacent to them. The percentage of mafic minerals also decreases near the ore zones. More than enough magnetite has been removed from the gneiss to account for the ore bodies. Ore formed by removal of primary accessory magnetite, by release of iron from mafic silicates and substitution by magnesium without breakdown of these minerals, and by release of iron during alteration and breakdown.

Around the small, scattered magnetite bodies in clinopyroxene skarn there is no gradual decrease in percentage of accessory magnetite or of mafic silicates, and clinopyroxene does not break down to alteration products with release of iron. Clinopyroxene also shows no decrease in iron; it is, however, lower in iron than that outside the mapped area. Magnetite in the skarn deposits formed by recrystallization of iron-rich clinopyroxene and hornblende to clinopyroxene relatively poor in iron.

PALEOGEOGRAPHIC EVOLUTION OF THE LAKE SUPERIOR AREA FROM LATE KEWEENAWAN TO LATE CAMBRIAN TIME

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A combined study of regional stratigraphy, petrology, and paleocurrents was made of the Freda sandstone (Upper Keweenawan), the Jacobsville-Bayfield sediments (Cambrian or Precambrian?), and the Dresbach and Franconia formations (Upper Cambrian). Data pertaining to the location and nature of the sources of these sediments were obtained primarily from petrology and directional sedimentary structures. Environmental reconstructions were based on patterns of lithologic variations, kinds of sedimentary structures, and heavy minerals.

This information indicates that the Killarney Mountains extended through northern Wisconsin and northern Michigan and were the major source area from Late Keweenawan to Dresbachian time. The Freda sandstone accumulated in a flood-plain and lacustrine environment north of the Killarney Mountains approximately in the present site of Lake Superior. Deformation followed Freda sedimentation and reduced the size of the depositional basin. Jacobsville and Bayfield sediments represent fan deposits merging northward from the Killarney Mountains into sediments of an alluvial plain. During Dresbachian time shallow seas invaded the area from the south and northwest but did not completely cover the Killarney Mountains. Dresbach sediments accumulated primarily in a beach environment, although in southern Wisconsin an offshore neritic environment predominated. Widespread regression of the seas followed, and most of the region was subjected to subaerial erosion. By Franconian time the Killarney Mountains were reduced to a surface of low relief, and the seas transgressed rapidly across the area from the southwest. Most Franconia sediments represent an offshore environment.

ORIGINAL BEDROCK COMPOSITION OF WISCONSIN TILL IN CENTRAL INDIANA*

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An attempt has been made to convert the mineral components of a till into the original bedrock materials from which the minerals were derived. The till used was a composite one (the "typical" till) that represented the averaged fraction-analysis data for 11 highly similar till samples from Marion County, Indiana. For this study, it was assumed that: (1) the glacier flow unit that reached Marion County was 20 miles wide and coincided with a series of interconnected bedrock lowlands lying between central Indiana and Lake Naococane, Quebec; (2) the flow unit eroded bedrock (or older drift) continuously throughout its journey from Lake Naococane; and (3) the different shales traversed by the ice were eroded equally.

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In terms of weight per cent composition, the typical Wisconsin till in Marion County probably consists of about 30 per cent shale, 28.5 per cent metamorphic rock, 18 per cent limestone, 17 per cent dolomite, 2.5 per cent igneous rock, 2 per cent sandstone and siltstone, and 2 per cent miscellaneous rocks. Approximately 90 per cent (by weight) of the typical till may consist of bedrock from outcrops more than 100 miles upstream from the site of till deposition.

An approximate 1:1 relationship has been found between the weight per cent of a given rock type in the typical till and the per cent of outcrop area of that rock type upstream. If valid, two implications of this relationship are that the Marion County tills were not deposited by lodgement processes and that the ice streams that developed them actually travelled 1200 miles.

CONODONT FAUNAS FROM THE DEVONIAN OF NEW YORK AND PENNSYLVANIA

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The pre-Conewango Upper Devonian succession between northwestern Pennsylvania and Ithaca, New York, contains at least six conodont faunal associations. Some characteristics of these faunas follow:

1. *Cassadaga* (youngest)—Greater part, Cooper's Cassadaga stage—*Palmatolepis perlobata, Polylophodonta confluens, Ancyrodella bifurcata, Panderodella truncata*—L. Famennian

2. *Chemung*—Cooper's Chemung stage and overlying Dunkirk shale member of Perrysburg fm.—*Palmatolepis subrecta, Ancyrognathus asymmetrica*—Frasnian, to Iδ

3. *Rhinestreet-Parrish*—Rhinestreet shale member of West Falls fm.; Parrish ls. bed of Cashaqua shale member of Sonyea fm.; and related beds—*Palmatolepis punctata, Ancyrodella nodosa*—Frasnian, to I(β)γ

4. *Standish*—Middlesex shale member of Sonyea fm.; upper part of West River shale member; and near Cayuga Lake upper part of Ithaca member of Genesee fm.—*Ancyrodella rugosa, Ancyrodella lobata*—Frasnian, to I(β)γ

5. *Genundewa*—Genundewa limestone member of Genesee fm. and adjacent beds; Crosby ss. of Torrey and adjacent beds near Keuka Lake; middle part of Ithaca member near Cayuga Lake—*Ancyrodella rotundiloba*—Frasnian, to I(β)γ

6. *Pre-Genundewa* (oldest)—Upper part of Geneseo shale member, Sherburne flagstone member, Renwick shale member, and, also, near Cayuga Lake, lower part of Ithaca member of Genesee fm.—Sparse conodont fauna includes long-ranging *Polygnathus pennata*. Fauna lacks species characteristic of younger Genundewa fauna as well as other species characteristic of older, M. Devonian, Tully limestone and Windom member of Moscow shale—Frasnian, to Iα

Part of Geneseo shale placed in Middle Devonian. Leicester marcasite herein regarded as transgressive basal bed of Genesee formation; Leicester oldest east of Canandaigua Lake where deWitt, Colton and writer found it above Tully limestone and youngest in western New York where on Eighteen Mile Creek, Erie County, it includes Hinde's (1879) "Conodont bed"; its fauna there is mixture of high Middle and low Upper Devonian (pre-Genundewa and Genundewa) conodonts.

Herein, deWitt and Colton's Genesee formation nomenclature used.

STRUCTURAL AND COMPOSITIONAL CONTROLS IN ARTIFICIAL WEATHERING

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The alteration to clays and zeolites of a series of rock types varying in silica content has been studied under hydrothermal conditions below 400°C. Natural glassy and crystalline rocks and syn-

thetic glasses and gels, ranging from granitic to basaltic compositions, have been reacted in sealed noble metal systems in neutral, CO_2-saturated, saline and acid environments.

The following factors have a significant effect on the products:

(1) Structure of the starting materials: Assuming the same composition of crystalline rock, glass, and gel, the glass reacts most easily and has the greatest predisposition toward zeolite formation, with a specific preference for analcite.

(2) Silica content markedly affects the rate of weathering; rhyolite perlites are completely resistant to change in the p-t range studied after 2 weeks in a *neutral* environment. However, the addition of controlled small (1, 2, 4, 8% by weight) amounts of MgO caused a remarkable acceleration in weathering of the rocks, including those highest in silica, with the formation of montmorillonoid predominant.

(3) In the presence of saturated CO_2 solution the glassy rocks yield predominantly illite over montmorillonoid and zeolite.

STRATIGRAPHIC CLASSIFICATION WITH REFERENCE TO COALS AND COAL-BEARING SEDIMENTS

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Coal strata are normal constituents of much of the earth's stratified rock sequence and as such are amenable to the same principles of stratigraphic classification as other kinds of stratified rocks. Quantitatively coal is not one of the most abundant of rock types, but on the other hand it is relatively distinctive. Individual coal units may occasionally attain member or even formation rank in lithostratigraphic classification, but more commonly the influence of coal on units of this scale is seen in the interbedding of coal strata with those of other lithologic types to give coal-bearing members or coal-bearing formations.

Because of their distinctive character and commercial value, however, coals are also particularly useful in lithostratigraphic classification as individual coal beds, and they serve to point up the importance as a lithostratigraphic unit of the term bed. Coal beds play a prominent role in stratigraphic classification as key beds, boundary markers, time-correlation horizons, recorders of biostratigraphic data, and indicators of environment. Recommended procedures for the handling of stratigraphic classification and terminology with respect to coals are outlined here through comments on practice in various coal regions and through hypothetical examples.

STRUCTURE AND PETROLOGY OF SALIC PLUTONS IN THE DEER LAKE AREA, NORTHERN ONTARIO, CANADA*

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Two concordant, composite stocks and part of a large, batholithic complex intrude a steeply dipping, typical Precambrian greenstone sequence. The three plutons may represent the upward movement of basement materials which acquired mobility in a zone of partial or complete melting at depth, during regional deformation. The bodies were forcefully emplaced as evidenced by pronounced structural dislocations in the country rocks adjacent to each pluton. The absence of contact metamorphism around the plutons indicates that they were emplaced in a p-t environment that was essentially that of the almandine amphibolite facies of the regional metamorphic terrain. The monzodiorite and monzonites were undoubtedly intruded as viscous, crystal–liquid mushes. The well-

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developed, primary mineral foliation, absence of chilled contacts, paucity of monzodiorite and monzonite dikes, and numerous evidences of strain in mineral grains in these rocks support this idea. Granitic material, with more mobility than the earlier emplaced units, completed the main intrusive activity in each stock. Small altered mafic bodies in the stocks are interpreted as reworked greenstone inclusions which were incorporated in their respective hosts at deeper crustal levels.

Provisional absolute age determinations (K/A and Rb/Sr methods) on three samples from the plutons are broadly concordant and suggest that the uprise of salic plutonic bodies occurred on the order of 2600 to 2700 million years ago in this area.

LITHIUM-TANTALUM PEGMATITES OF THE SÃO JOÃO DEL REI DISTRICT, MINAS GERAIS, BRAZIL

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The spodumene pegmatites of the Volta Grande area, São João del Rei district, Brazil, display structural and mineralogical characteristics that place them intermediate to the essentially unzoned "Kings Mountain" type of North Carolina and the well-zoned "Etta" type of the Black Hills. Most of the dikes display indistinct zoning with a thin border zone and a central spodumene-bearing unit and in some examples with a poorly defined microcline core. Deep weathering further obscures the zonal delineation. Parts of some dikes are characterized by repetitive comb-structure layering of spodumene laths which have their c axes nearly normal to planes or gently curving surfaces that are generally parallel with wall-rock contacts. In addition, units of contrasting grain size (but not mineralogy) may be developed asymmetrically. Post-consolidation structures, which are greatly subordinate, consist of narrow veins of muscovite, of quartz, and of feldspar.

The minerals of the dikes are: (major) microcline, sodic plagioclase, quartz, spodumene, muscovite; (minor) cassiterite, tantalite, microlite (var. "djalmaite"), ilmenite, magnetite, lepidolite; (rare) schorl, garnet, bityite, zircon, xenotime. Both the tantalite and microlite are tantalum rich, the latter containing as much as 74.4 per cent Ta_2O_5 and also 4.37 per cent $UO_2 + UO_3$. Cassiterite and the two tantalum minerals are recovered economically from an operation that consists of washing strongly kaolinized pegmatite from the larger dikes.

Spodumene pegmatites are post-tectonic, whereas a pre-tectonic group of dikes, which exhibit marked fracturing and crushing, are spodumene free, contain columbite instead of tantalite, and have little or no microlite.

COPPER-ZINC SKARN DEPOSITS IN SOUTH-CENTRAL COLORADO

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A number of geologically and mineralogically similar copper-zinc skarn deposits that occur from Salida to the Colorado Front Range have been re-examined. Of these, the most famous is the Sedalia mine described by Lindgren in 1907. Two deposits, the Betty, near Guffey, and the Cotopaxi, just northwest of Cotopaxi, have been studied in detail. Paragenetic studies on Cotopaxi skarns serve also to illustrate the nature of the mineralization in the other deposits.

The Cotopaxi is an irregular lens, about 300 by less than 50 feet, set in a 1½ by 2 mile xenolith of Idaho Springs rocks within Pikes Peak granite. Mineralization is confined to an amphibolite layer between hanging-wall biotite gneiss and footwall sillimanite gneiss. During Stage I of the development of the deposit the amphibolite was reorganized into coarse foliated aggregates of anthophyllite, actinolite, garnet, thulite, clino-humite, forsterite, and scapolite. This phase was

succeeded by the generation of a pegmatoid of quartz, oligoclase, garnet, phlogopite, and gahnite. In the third (ore) stage, molybdenite (minor), sphalerite, chalcopyrite, pyrite, and galena replaced the skarn species and filled fractures. During the final stage chlorite and sericite replaced earlier high-temperature silicates. Lindgren believed the deposits to be magmatic; the geology and mineralogy, however, suggest a pyrometasomatic environment in rocks of high-grade metamorphic character.

GEOLOGIC AGE DETERMINATION BY X-RAY FLUORESCENCE ANALYSIS FOR RUBIDIUM AND STRONTIUM

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The capabilities of X-ray fluorescence spectroscopy (XRF) for rubidium/strontium ratio determination have been investigated, using a suite of lepidolites whose Rb and Sr contents had previously been determined by mass spectrometric isotope dilution (MSID) and neutron activation analysis. In these samples, Rb ranges between 1.5 and 4.0 weight per cent and Sr between 7 and 300 ppm.

It was found that the method is an excellent rapid reconnaissance tool (several analyses can be made in one day) which can in addition, for Precambrian and early Paleozoic samples, often by itself yield useful ages. For example, XRF age determinations of five samples from Brown Derby, South Dakota, ranged between 1360 and 1406 m.y. with an average of 1390 m.y., while six MSID analyses range between 1350 and 1415 m.y. with an average of 1384 m.y. Since essentially all the strontium in lepidolites is radiogenic ^{87}Sr, the elemental Rb/elemental Sr ratio by itself gives the age; Sr isotope abundance determination is not necessary.

The potassium content of these samples (ranging from 5 to 10 wt.%) was also determined. For this purpose, X-ray fluorescence appears to compare well with neutron activation, flame photometry, and spectrography. But XRF has the advantages of requiring no chemical processing and of being nondestructive; samples may be analyzed as often as is desired.

ADSORPTION OF ORGANIC MOLECULES FROM AQUEOUS SOLUTIONS ON MONTMORILLONITE

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The adsorption of neutral, nonionic organic molecules from aqueous solutions on Ca-montmorillonite has been studied in order to obtain information on the adsorption process unobstructed by any exchange reactions. The choice of organic substances is limited by their solubility in water. Adsorption isotherms of various types were obtained for several compounds of the following classes: 1,3—diketones, 1,4—diketones, esters, esters of polyethyleneglycols, polyethyleneglycols, and others. With increasing organic concentration the diketones showed progressively increasing adsorption, whereas the polyethyleneglycols and their esters reached a saturation adsorption.

Parallel X-ray studies of the clay–organic complexes were made, and 1-layer and 2-layer complexes were recorded and their spacings accurately measured. In all cases there was a marked tendency for the formation of regular 1-layer or 2-layer complexes in preference to mixed-layer formations. The spacings were taken from unwashed samples because the organic content was always more or less easily washed out. In consequence, the clay samples tend to take up additional organic material from the adherent solution during evaporation. Conversely organic material may evaporate from the clay during the drying process. Both processes change the composition of the clay–organic com-

plex from its condition in liquid suspension and preclude exact correlation of the X-ray data with the adsorption isotherms.

BRACHIOPODA OF THE OSWAYO AND KNAPP FORMATIONS OF THE PENN-YORK EMBAYMENT

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The abundant brachiopod faunas of the Oswayo and Knapp formations of the great Devono-Mississippian or "Catskill" Deltaic Plain of the Penn-York Embayment are re-evaluated to determine the proper placing of the boundary between the Devonian and the Mississippian. The brachiopods were collected principally in northwestern Pennsylvania from the Oswayo and Knapp formations of the Big Bend magnafacies in order to minimize facieological differences. The Tidioute shale, previously thought to overlie the Knapp, is believed to belong to the next western magnafacies, the Chagrin; brachiopods of this formation were collected where it interfingers with the Knapp.

In all, 47 species, subspecies, and morphological variants are described. These are classified into 25 unquestioned species in 17 genera of which 1 is new. One new subgenus is also described. Of the 25 species occurring in these formations, 15 are new.

Based upon differences in lithology, the presence of a slight disconformity, and upon considerable differences in the brachiopod faunas including (1) diminution in number and variety of forms in some genera, (2) first occurrence or rapid expansion of other genera which could be Devonian as well as Mississippian, (3) first occurrence in the Knapp of common Mississippian genera, and (4) considerable differences in the faunas caused by the addition of new species in the Knapp and Tidioute, the writer concludes that the Devonian–Mississippian boundary is correctly placed between the Oswayo and Knapp formations in the southwestern New York–northwestern Pennsylvania sector of the Penn-York Embayment.

LATE GLACIAL ICE-MARGIN ALIGNMENTS IN WESTERN NEW YORK

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Through the region south and southeast of Lake Ontario, no less than 20 successive glacier-front positions are recorded by marginal moraines and associated features, varying greatly from place to place, with many segments of weak topographic expression. They represent at least two Wisconsin substages (Cary and Mankato?). In the Finger Lakes region the series (about 14 marginal moraines) begins at the south (oldest) with the outermost Valley Heads deposits. The youngest extends across Oswego River a few miles south of the Ontario shore.

Marginal alignments show strongly the effects of melting by proglacial ponded water. As noted by Leverett, only slight recession occurred above lake level at the plateau salient near Alden, while the high-level waters immediately to the west drove back the glacier margin many miles toward the Ontario basin, thus giving the marginal moraines a fanlike areal pattern. A similar radial alignment has its apex against the plateau heights between Genesee Valley and the Finger Lakes sag; likewise still younger moraines fan northwestward from the plateau escarpment near Syracuse, the place of final ice-front retreat from the plateau.

Across the northern portions of Genesee, Seneca, and Cayuga valleys the moraines show no southward lobation, which also is attributed to effective melting by the impounded water.

Near Auburn, and in a few other localities, a series of low, inconspicuous ridges, transverse to drumlin axes and spaced a few hundred feet apart, are believed to be "washboard-type" moraines.

GLACIATION IN THE JOHNSON RIVER–TOK AREA, ALASKA RANGE

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The largest Pleistocene glaciers in this area were piedmont ice sheets in the Gerstle, Johnson, and Robertson River drainage basins. Scores of smaller glaciers were tributary or developed as cirque, hanging, or piedmont glaciers. The most extensive records occur in small valleys, particularly those facing northeast. Independent plateau glaciers, and small highland ice caps, partly nourished from cirques along the mountain crest, developed on flat uplands in the Johnson River area. Several outlet glaciers flowed from these sources.

Three major glaciations are recorded: Delta, Donnelly, and a younger advance in high northeast-facing cirques, plus one minor glaciation, a recent advance a short distance from present glaciers. Delta moraines have modified knob-and-kettle topography and till that is oxidized through more than 5 feet. Donnelly moraines are marked by deep, closely spaced kettles and sharp knobs, and the till is oxidized to less than 2.5 feet. Deposits of the younger glaciation are slightly weathered and are separated from the Donnelly moraines by bouldery outwash plains. These moraines are larger and more weathered than those in contact with or near the present glaciers.

Outwash was deposited on steep piedmont surfaces sloping to the present level of the Tanana River. Glacio-fluvial deposits of different glaciations were superimposed on one another and typically do not occur in distinct flights of terraces. This suggests that the streams rapidly lost competence as they flowed toward the Tanana, as do the present mountain streams, and that the Tanana River has maintained an essentially stable position in relation to these tributaries.

RELATIVE STABILITIES OF SOME ZEOLITES

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The relative stabilities of the following zeolites have been studied under hydrothermal conditions from 150° to 400°C. and 1000–2000 atm.: phillipsite, gismondite, harmotome, chabazite, and gmelinite, each saturated with each of the following cations in the exchange positions: Na^+, K^+, Ca^{++}, Ba^{++}. In addition, Linde Type A zeolite and faujasite saturated with Ca^{++} and Na^+ ions were investigated.

The data show the following:

(1) Phase transformations from members of the chabazite group to those of the phillipsite group can be effected more easily than transformations within the same group. For example,

$$\text{Ba gmelinite} \xrightarrow[1000\text{ atm}]{250^\circ\text{C}} \text{harmotome}$$

$$\text{Na chabazite} \xrightarrow[1000\text{ atm}]{180^\circ\text{C}} \text{phillipsite}$$

$$\text{Ca type A} \xrightarrow[1000\text{ atm}]{200^\circ\text{C}} \text{natrolite (Note synthesis of natrolite and temperature limit imposed on "wet" heating of Ca Type A for "regeneration.")}$$

$$\text{Ca, Ba, K gismondite} \xrightarrow[1000\text{ atm}]{300^\circ\text{C}} \text{natrolite}$$

$$\text{Na-Type A, Na, Ca-faujasite} \xrightarrow[1000\text{ atm}]{\text{slightly below } 200^\circ\text{C}} \text{phillipsite} + \text{analcite}$$

(2) Na phillipsite transforms to analcite at least as low as 250°C. (at 1000 atm), whereas the Ca and K phillipsites persist to over 350°C. These data are of interest when correlated with the geological observation that marine phillipsites are found only in sediments younger than mid-Tertiary.

(3) Several zeolites yield "amorphous" phases (even under high water-pressure conditions for 1 week) as intermediate steps in the transformations, *e.g.*, Ca, Ba, K chabazites at 250°C., Ca phillipsite at 330°C. (all at 1000 atm). Furthermore, a rock sample containing much natural faujasite (Stempel near Marburg, Germany) included several euhedral, milky-looking cubes which on X-ray examination proved to be "amorphous". The cubes were hydrothermally recrystallized to phillipsite.

DIELECTRIC BEHAVIOR OF ROCKS AND MINERALS

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Determinations of dielectric constant were made on 25 mineral samples and 45 dry-rock samples over the frequency range of 50 cycles to 30 megacycles. These included minerals in both monocrystalline and polycrystalline form and rocks of sedimentary, igneous, and metamorphic origin. Studies were made of 31 samples from three sedimentary formations to show the effects of bulk moisture on dielectric constant.

The dielectric constants of dry rocks and minerals when measured as a function of frequency fell into two categories: those showing considerable dispersion at low frequencies, and those showing little or no dispersion over the entire spectrum studied. The mineral samples which showed no dispersion were in most cases of high purity. Polycrystalline monomineralic aggregates and poorly crystallized simple crystals showed varying degrees of dispersion, as did the dry polymineralic rocks. Two polarization mechanisms are presented to account for the observed dielectric behavior. These are ion migration over films of tightly adsorbed water, and ion migration in crystalline material along submicroscopic paths resulting from imperfections within its structure.

For sandstone samples containing bulk water, anomalously high values of dielectric constant and strong dispersion were observed at the lower frequencies. This is in general agreement with the theory developed by Maxwell and Wagner for laminated dielectrics.

RECENT IDEAS ON THE ORIGIN OF UNDERCLAY SEAT EARTHS

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Although recent papers have suggested that underclays are not soils but represent materials altered to clay elsewhere, sorted, and deposited in swamps, field and laboratory evidence shows that the simplest and best explanation of seat earths is that they are old soils developed in place in swamp environments from the available parent material and modified by chemical changes during peat accumulation and coalification. Underclays and other seat earths contain roots, have profiles similar to water-logged soils, lack bedding, have structure similar to soils, and grade downward into normally bedded rocks. The range from impure to nearly pure quartz seat earths (ganisters) and from plastic underclays to poorly crystalline, and thence to well-crystallized kaolinite and diaspore-bearing flint clays suggests degrees of alteration in place. Delicate vermiform crystals of kaolinite and pseudomorphs after feldspar, found in seat earths and coal-bed partings, indicate that kaolinite formed in swamps. The gradual increase in titania content from that in plastic underclays to that in the well-crystallized more kaolinitic underclays suggests residual accumulation, because it is unlikely that winnowing would deposit heavy titania-bearing minerals preferentially with either the light illitic or kaolinitic clays. Differences in seat earths can be explained by differences in parent material, degree of leaching, and by a succession of chemical environments in the swamp before, during, and after peat accumulation. Changes in chemical environment are indicated by the growth

and resolution of quartz and kaolinite grains and by the presence of chlorite, probably formed in place.

AUTHIGENIC VERSUS DETRITAL ILLITE IN SEDIMENTS

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Illite in modern sediments contains amounts of radiogenic argon 40 that indicate that the illite frequently has been formed originally in an earlier cycle of sedimentation. Collaborative studies are in progress with the following: Bruce Nelson on the illite in the Rappahannock River and its estuary; H. N. Fisk and Milton Williams on the sediments of the Mississippi delta; Cesare Emiliani, Bruce C. Heezen, Wallace S. Broecker, and P. H. Kuenen on pelagic sediments from various oceanic regions; and J. M. Hunt on illite in well-dated ancient sediments. Results to date indicate that mid-continental wind-blown material (Mississippi loess) reflects the early Paleozoic age of the sediments in the dust-bowl area, and that illite in soils forming from the weathering of illitic sediments shows the same age as the underlying source rock. The illite and K-bearing material in the Rappahannock River sediments has an age in excess of 300 m.y. The aggregate materials of the Mississippi Delta show ages in excess of 200 m.y., with a reddish-brown horizon at depth in a drill hole reaching 800 m.y. This is believed to have been deposited by the Red River. Pelagic illitic clays from deep ocean cores and bottom samples show various ages that suggest an air-borne derivation from continental source areas.

A^{40}/K^{40} AGE DETERMINATIONS OF ROCKS ASSOCIATED WITH NORTH END OF PIKES PEAK BATHOLITH, JEFFERSON, DOUGLAS, AND PARK COUNTIES, COLORADO

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A^{40}/K^{40} ages on biotite have been determined for (1) an arcuate septum of hornblende granodiorite within the outer granite zone on the northwest side of Pikes Peak batholith; (2) Doublehead pluton which is a satellite intrusion of Rosalie Lobe of the north end of Pikes Peak batholith, and (3) Kenosha batholith in South Park several miles west of Pikes Peak batholith. Samples (1) and (2) are adjudged temporally, spatially, and genetically probably related to, and sample (3) not related to, Pikes Peak batholith.

Sample (1), hornblende granodiorite, is 1050 million years; sample (2), muscovite-biotite-quartz monzonite, is 1240 million years; and sample (3), biotite-muscovite-quartz monzonite, is 1300 million years. Constants used are $\lambda_e = 0.589 \times 10^{-10}$ yr. and $\lambda\beta = 4.76 \times 10^{-10}$ yr.

Textural and field relations of sample (1) to surrounding outer-zone granite of Pikes Peak batholith suggest that the granodiorite was intruded by the granite. This granodiorite is identical in age (1050 million years) and almost so in composition to a much larger mass 5 miles to the east toward the interior of the batholith. The larger mass is cogenetic with the Pikes Peak batholithic rocks.

Structural, tectonic, and petrographic features of Doublehead pluton in relation to Pikes Peak batholith indicate it was a precursive, fingerlike, concordant intrusive phase to the final later emplacement of the much greater mass that is Pikes Peak batholith.

Kenosha batholithic activity resulted in varyingly intense, predominantly concordant granitization, pegmatization, and *lit-par-lit* injection of metamorphic framework rocks. All these features are discordantly intruded by outer-zone granite along the west flank of Pikes Peak batholith.

GENERAL FEATURES OF STABLE-ISOTOPE RESEARCH, AS APPLIED TO PROBLEMS OF ORE DEPOSITS: INTRODUCTION

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Application of the studies of stable isotopes is still in its infancy, but the results to date hold great promise of providing new methods of attack on some very old problems of economic geology. Measurements of oxygen isotopic ratios of various minerals, particularly quartz, carbonates, and magnetite, may provide geologic thermometers and perhaps clues to the nature and origin of some ore-forming fluids. The isotopic composition of sulfur in sulfides and of hydrogen, oxygen, and carbon in thermal waters and fluid inclusions of ore minerals similarly may provide controls on concepts of ore-depositing solutions. The measurements of lead isotopes furnish a basis for fundamental studies of primordial metal distribution in the crust and, for ore deposits, a nongeologic means of differentiating between deposits that originated by magma fractionation and those derived by aggregation of metals from rocks traversed by hydrothermal solutions.

The number of qualified isotope geochemists available for this type of work is small, the equipment is costly, and many of the extractions and measurements are difficult and time consuming. This expenditure can be justified and this limited capacity properly exploited only if economic geologists and petrologists are willing to put equivalent or greater effort into defining the field problems, into proper selection of materials, and into the exceedingly complex problem of geologic interpretation of the results.

REGIONAL METAMORPHISM, FELDSPATHIZATION, AND GRANITIZATION IN EASTERN NEWFOUNDLAND*

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Eugeosynclinal sediments of the Middle Ordovician Gander Lake group in eastern Newfoundland have been regionally metamorphosed; the grade of metamorphism increases eastward from the Southwest Gander River. Tentative chlorite and biotite isograds have been outlined, both oriented approximately north-northeast almost parallel to the regional structure. Slightly athwart these metamorphic zones lies a group of post-folding intrusive and metasomatic granitic rocks, which form a belt 10–40 miles wide trending northeastward across the island. These rocks are largely flesh-red, coarse-grained to porphyritic biotite granites with perthitic K feldspar and abundant albite. Sharp contacts and contact metamorphic aureoles up to 1 mile wide occur along the west flank of the belt, where the granites lie within the chlorite zone. On the east flank of the granite belt, within the biotite zone, contacts are gradational with the adjoining paragneisses and mica schists, with considerable evidence of feldspathization, migmatization, and granitization. Large euhedral porphyroblasts of perthitic K feldspar occur here in both the metamorphosed Ordovician rocks and the Precambrain greenschists farther east; large areas of each are almost completely granitized. The regional metamorphism, feldspathization, and granitization are regarded as related to one plutonic period, which from field evidence occurred post- Middle Ordovician and pre-Late Devonian.

Potassium-argon ages on muscovite from two apparently intrusive granite bodies within the granite belt near Gander Lake have yielded 366 and 345 million years, comparable with the ages of micas from Nova Scotia granites, which are now interpreted as early Devonian intrusions.

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SULFUR ISOTOPES AND ECONOMIC GEOLOGY: A SUMMARY

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Sulfur isotopic studies have been useful as an economic geology "tool" because of the ubiquity and extensive isotopic fractionation of sulfur.

Sulfur from troilites exhibits a remarkably uniform S^{32}/S^{34} composition of 22.21 ± 0.02 (δS^{34} = 0.0 permil). Assuming that primordial earth sulfur had a similar composition, geologic processes have caused δS^{34} values for sulfides alone to range between +40.1 and −52.0 ‰.

Some observations made of the significance of δS^{34} studies are:

(1) Sulfides from magmatic hydrothermal deposits exhibit a very narrow spread in δS^{34}, generally near the troilite value.

(2) Sulfides from hydrothermal deposits not associated with an intrusive source exhibit a broad spread in δS^{34}.

(3) Nonequilibrium reduction of $SO_4^=$ to H_2S by anerobic bacteria results in a variable enrichment of S^{32} in the H_2S formed. This effective reducing agent can cause the concentration of numerous constituents such as U, Fe, and Cu, as it apparently has done in the formation of some epigenetic deposits where ore-bearing solutions have encountered this gas such as sandstone-type uranium deposits and "Red Beds" copper deposits, and in the formation of syngenetic sulfides including possibly the Rhodesian Copper Belt.

(4) Inorganic reduction of $SO_4^=$ to $S^=$ is quite rare. The abundance of carbon, however, with many of the New Brunswick, Canada, sulfides suggests the possiblity of reduction of $SO_4^=$, enriched in S^{34}, at high temperatures forming, therefore, sulfide deposits enriched in S^{34}.

(5) Oxidation of $S^=$ to $SO_4^=$ in hypogene solutions may be the cause of S^{34} enrichment in hypogene sulfates; in contrast, no detectable isotopic fractionation occurs during supergene oxidation.

EMPIRICAL CRYSTALLINITY INDEX FOR KAOLINITE

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In evaluating differences in the physical properties of kaolinitic clays, the need for a quantitative index of crystallinity is apparent.

The ratio of the relative intensities of the $(02\bar{1})$ and (060) kaolinite reflections (as indexed by Brindley) was chosen as the crystallinity index. This index ranges from 0.00 to about 1.00 as determined empirically by the study of a wide variety of kaolins, bauxitic kaolins, and flint clays of domestic and foreign origin. Preliminary studies indicate that there are two groups of kaolinites with crystallinity indices from 0.00 to 0.50 and 0.80 to 1.00. There appears to be a dearth of values between 0.50 and 0.80.

Georgia kaolins, usually considered to be of high degree of crystallinity, have indices throughout the range 0.00 to 0.50; the better crystallized kaolins have values around 0.50.

There is no consistent correlation between particle size and crystallinity, even among different size fractions of the same clay.

SCHOHARIE FORMATION REDEFINED

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Detailed stratigraphic and petrographic studies permit redefinition of the Schoharie formation. It is a complex of lithologic facies extending along the Devonian (Onesquethaw) outcrop from

Herkimer County, New York, at least to Monroe County, Pennsylvania. The formation thickens south to Port Jervis, New York, and thins again in New Jersey and Pennsylvania.

Two major subdivisions are recognized. The lower subdivision is calcareous mudstone and calcareous siltstone containing a sparse fauna made up of small forms. North of Kingston, New York, the base is locally marked by glauconite, whereas a persistent zone of *Leptocoelia acutiplicata* defines the base southward. In east-central New York the upper subdivision is sandy limestone and calcareous sandstone characterized by brachiopods and conspicuous orthoceracones. At places glauconite is abundant in its lower part. Southward this subdivision passes laterally into finer calcareous strata which are divisible into two subunits within New York State. The lower subunit, composed of calcareous siltstone with minor argillaceous limestone and calcareous sandy mudstone, carries abundant chert in the Mid-Hudson Valley. Within this same area the upper subunit is distinguished by conspicuous layers of limestone alternating with calcareous mudstone, calcareous argillaceous sandstone, and argillaceous limestone; farther south pure limestone is absent. The Schoharie–Onondaga contact is easily drawn wherever lowest Onondaga is biostromal. In southeastern New York, New Jersey, and Pennsylvania, where conditions of Schoharie and Onondaga sedimentation were more nearly alike, distinction is made partly on faunal and partly on petrologic grounds.

New subunit names are proposed in the hope of clearing previous errors in correlation.

POTASH DEPOSITS IN THE CARLSBAD DISTRICT, SOUTHEASTERN NEW MEXICO

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In the Carlsbad district, southeastern New Mexico, certain salt layers in the middle of the Salado formation (upper Permian) contain potash deposits. The deposits lie near the western margin of the Permian salt basin at depths ranging from 340 to 2650 feet below the surface. They underlie about 900 square miles, almost equally divided between the structurally low Delaware Basin in the south and the higher standing Northwestern Shelf in the north.

The rock salt of the Salado formation accounts for half of a 4500-foot section of marine evaporites and separates anhydrite of the Castile and Tansill formations (upper Permian) from younger evaporites of the Rustler formation (upper Permian). Overlying the evaporites are strata, of different thicknesses, of Late Triassic and Cenozoic age.

The potash deposits are stratigraphically controlled and formed by replacement of interlayered halite and argillaceous halite rocks by bittern salts comprising various chlorides and sulfates of potassium, magnesium, and sodium. These salts form discrete, superposed, mantolike deposits having sharp outlines against the unmineralized host rock. Bedding planes extend uninterrupted from halite rock into the "mantos", although thin laminations within individual layers were destroyed in the course of recrystallization accompanying deposition of the bittern salts. The laminations, however, appear within small isolated remnants and large islands of halite rock enclosed by the "mantos".

Structural relations and stratigraphic distribution provide evidence in support of an epigenetic origin for the deposits. Metasomatism by reaction of residual potassium- and magnesium-rich bitterns with pre-existing halite rock is favored.

OBSERVATIONS ON IGNEOUS INTRUSIONS IN LATE PERMIAN EVAPORITES, SOUTHEASTERN NEW MEXICO

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In the Carlsbad district, southeastern New Mexico, potash deposits and rock salt in the Castile and Salado formations (upper Permian) are cut by a northeasterly trending system of thin, steeply

dipping dikes of basalt and a dolomite-rich, alkalic intrusive rock. An alkalic dike, exposed at two places on the lowest level of the International Minerals and Chemical Corporation's mine, changes abruptly upward and laterally to a vein of polyhalite. Structural data suggest that the basalt and the alkalic dike rock are genetically related.

The alkalic dike is a medium-gray, porphyritic aphanite. Lath-shaped phenocrysts of sodic plagioclase, dolomite rhombs, and small amygdules containing dolomite and natrolite are set in a holocrystalline groundmass composed dominantly of orthoclase with biotite and accessory ilmenite. The rock exhibits flow structure and has a chilled border against the invaded salt. Intersecting vertical and near-horizontal fissures containing fibrous polyhalite and halite with accessory pyrite and hydrocarbons give the dike an unusual "ladderlike" structure.

The rock salt is bleached and recrystallized for ½ to 1½ inches from the contact. Epigenetic pyrite, polyhalite, and hydrocarbons were introduced by aqueous solutions that moved upward through fissures which cut the dike rock. The late aqueous solutions leached hematitic sylvite, formed blue halite, and converted langbeinite to kainite and bloedite for a distance of 5 inches from the dike in invaded potash deposits.

SPHALERITE TEMPERATURES FROM THE BRUNSWICK AND NIGADOO DEPOSITS, NEW BRUNSWICK, CANADA

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The Brunswick lead-zinc-copper deposit is a large, lenticular, massive, fine-grained replacement, consisting essentially of pyrite with galena and sphalerite. Along the footwall an adjoining zone contains pyrrhotite, chalcopyrite, and little sphalerite and galena. Twenty-five sphalerites from this deposit were analyzed for iron by X-ray-fluorescence techniques. Where pyrite is the chief iron sulfide the iron content in the sphalerite ranges unsystematically from 8.5 to 12 per cent FeS (295° to 400° C.). In the part containing pyrrhotite the iron content is consistently higher, near 13.5 per cent FeS (430° C.). This relationship is in complete accordance with theory.

The Nigadoo deposit is a coarse-grained xenothermal vein. In an unpublished paper Aleva describes a deeper zone of pyrrhotite grading upward into marcasite and pyrite. The most abundant of the associated minerals are calcite, sphalerite, galena, chalcopyrite, arsenopyrite, lollingite, and stannite. Fifteen sphalerites from various associations show a 3.5 per cent spread of FeS content, in the range considered tentatively to be from 20 to 23.5 per cent FeS (580 to 650° C.). Nine of the sphalerites show a content of about 0.5 per cent Mn and from 0.6 to 0.9 per cent Cd. The reason for the variation in iron content is obscure.

The above deposits are geologically similar respectively to Heath Steele and to Sturgeon River. Sphalerite from the former gives values near 325° C. and for the latter near 590° C.

PETROFABRIC OBSERVATIONS ON ICE FROM BLUE GLACIER, WASHINGTON, IN RELATION TO THEORY AND EXPERIMENT

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Three textural types of ice, intercalated to form the foliated structure of the bulk ice, are recognized on Blue Glacier: coarse bubbly ice, coarse clear ice, and fine ice. Fine ice shows consistently a broad single maximum in c-axis-orientation density, centered about the pole of the foliation plane. This fabric is related to fabrics of stressed ice from polar glaciers, and the fine ice layers resemble layers recently produced in the laboratory by rapid shearing deformation of glacier ice. The writer infers that the fine ice layers in the glacier constitute zones that have undergone rapid mechanical plastic flow, and that the adjacent coarse ice layers originate by recrystallization from fine ice.

Coarse bubbly ice fabrics generally show several maxima in c-axis-orientation density. The statistical significance of multiple-maximum fabrics is tested by comparison of several independent fabrics from given stress situations, and the writer shows that the "diamond"-shaped four-maximum pattern is reproducible, though subject to unexplained fluctuations in orientation. This fabric is characteristic of ice subjected to shear stress of persistent orientation, and the long axis of the "diamond" is (approximately) parallel to the direction of the stress vector that acts across the persistent plane of maximum shear stress.

Results of recent experimental studies of the origin of ice fabrics are in moderately good agreement with the Blue Glacier observations. Recent theoretical treatments are in sufficient disagreement to be ruled out.

REASSESSMENT OF RADIOCARBON DATING AND CORRELATIONS OF STANDARD LATE PLEISTOCENE CHRONOLOGIES

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Because of conflicts in Pleistocene correlations, standard late Pleistocene events can be definitively radiocarbon-dated only from deposits closely associated with type moraines. Dated type-locality stratigraphy confirms other geologic relations in support of the following correlations:

(1) Des Moines lobe type Mankato Bemis and recessional Altamont moraines with Great Lakes Port Huron moraines (all dated between 10.8 and 9.5*) demonstrating Leverett and Leighton's original definition of Cary-Mankato interstadial, not its redefinition as Two Creeks, post-Bemis, pre-Altamont (pre-Valders). Thus Mankato maximum (Bemis-Port Huron) with Swedish Gothenburg advance (varve-dated 10.3-10.0*), not with younger Fennoscandian oscillations of Valders subage.

(2) In Illinois, type Cary moraines predate recessional Wabash moraine dated pre-12.4,* type Tazewell (Shelbyville) maximum dates 17.2-16.5*, underlying pro-Wisconsin loess dates 18.4*, and older type Farmdale loess dates 23.2-21.0*; in accord with parallel sequence and varve and radiocarbon dating of pre-Gothenburg European sequence of Scanian (maximum 13.0*), Pomeranian (pre-13.7*), Frankfort von Posen, and Brandenburg (after pre-21.0*).

These dated glacial sequences agree with the independently dated Alaskan glacial chronology and with other paleoclimatic records now available from widely separated North Hemisphere regions. These parallel sequences strengthen the case for climatic synchronism, the fundamental assumption underlying Pleistocene classification and correlation.

The agreement between radiocarbon-dated and the Swedish varve-dated sequences indicates that, for all practical dating purposes, the C-14 year may be assumed equivalent to varve and calendar years; thus the conversion from C-14 B.P. to varve B.C.-A.D. convention for comparison purposes.

PALEOZOIC STRATIGRAPHY IN THE GARNET RANGE, WESTERN MONTANA

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The Garnet Range contains some of the most westerly exposures of Paleozoic rocks in Montana and the entire Rocky Mountain region. A total of approximately 7000 feet of Paleozoic strata is divided as follows: Cambrian 1900–2850 feet, Devonian 2100 feet, Mississippian 2200 feet, Pennsylvanian 450 feet, and Permian 0–290 feet.

The Flathead quartzite, Silver Hill formation, and lower part of the Hasmark formation con-

* B. C. dates in thousands of years.

stitute the Middle Cambrian; the upper Hasmark and the Red Lion formation constitute the Upper Cambrian. No Ordovician or Silurian strata are recognized in the Garnet Range.

The Devonian system includes the Maywood, Jefferson, and possibly the Three Forks formations. The Mississippian is composed of the Madison group (Lodgepole and Mission Canyon formations) and the lower part of the Amsden formation. The upper part of the Amsden and the Quadrant formation are Pennsylvanian strata. The Permian Phosphoria formation is the youngest Paleozoic stratum in western Montana.

Paleontologic and physical evidence indicates that the Silver Hill formation correlates with the Wolsey shale of central Montana; the Hasmark formation correlates with the Meagher limestone, Park shale, and Pilgrim limestone of central Montana; the Red Lion formation correlates with the Dry Creek shale and the Snowy Range formation of central Montana.

The upper Paleozoic formations have yielded few diagnostic fossils in the Garnet Range but can be reasonably well correlated with other parts of Montana on their distinct lithic characteristics. Fossils collected from the formations have been used in determining the most probable ages.

DEFORMATION OF THE ROSS ICE SHELF, CAMP MICHIGAN, BAY OF WHALES REGION, ANTARCTICA

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Stake systems were surveyed at Camp Michigan to establish their relative positions on successive dates and thereby define the strain-rate tensor field for the area.

Under normal conditions, folds form with their axes perpendicular to the direction of principal compression, but deviations up to 20° have been recorded. In all cases examined, the aberrant fold appears to have been superimposed on a pre-existing crevasse field. It is also believed that the areas in which these folds appear are undergoing considerable rotations.

When the compressive strain rate is approximately equal to the extensional rate (pure shear), the crevasses lie perpendicular to the principal tensional axis. However, as the compressive rate increases significantly over the tensile rate, the strike of single crevasses ranges in orientation from 0° to 40° with respect to the principal axes of compression. It is not possible to draw the trajectories of the strain rate tensor simply on the basis of the geometry of crevasse fields, nor is it possible to use a fixed minimum value of the extensional rate as the necessary and sufficient condition for crevasse formation.

No existing laws concerning the mechanical behavior of materials seem adequate to explain the observed phenomena, but with the great variety of data available from the Ice Shelf structures, the formulation of a more generalized and adequate behavior law for ice may be possible.

CHARACTER OF THE OAK SPRING FORMATION (TERTIARY)

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All underground nuclear explosions in the kiloton range at the Nevada Test Site have been conducted in the volcanic tuffs of the Oak Spring formation of Tertiary age. The formation is about 2000 feet thick and is composed of welded tuff and fine- to coarse-grained nonwelded tuff. All are rhyolitic to quartz latitic, and, with the exception of the devitrified welded tuffs, the rocks contain abundant zeolite.

The rocks near the explosion points are white to maroon brown, thin- to thick-bedded vesicular, fine- to coarse-grained tuff. They consist of phenocrysts which are principally quartz, K feldspar, and plagioclase, and xenoliths of metavolcanic and metasedimentary rocks. The groundmass is

composed of lapilli and shards altered to heulandite, beta cristobalite, montmorillonitic clay minerals, and minor amounts of glass, quartz, and mica.

In the natural state the rocks are nearly, if not completely, saturated with water, although some fractures cutting the rocks are dry or yield only small amounts of water. The average porosity is about 30 per cent; the bulk density about 1.9 gm/cc; the compressional velocity about 8000–10,000 ft/sec; and the compressive strength about 2000–5000 psi. At confining pressures greater than about 5000 psi the high-zeolite tuff will deform to strains of at least 20 per cent without rupture.

CONCEPT OF OPERATIONAL MECHANICS IN FOLDING

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In the analysis of large folds it is common to consider a single more or less fixed system of stresses and a regional motivation of deformation in terms of existing dimensions and form. More attention might be given profitably to the evolution of the structure by stages.

The growth of folds may be termed operational mechanics, which involves interpretations or postulations as to the sequence of deformations. For example, a large basin may have had its present area from the beginning, with growth changes involving only its rims; or it may have grown centripetally from a small basin; or it may have formed by coalescence of lesser basins. Similarly an anticline 20 miles long may have developed (originally) along its full length to its present height, or it may have grown lengthwise from a shorter fold. Curving folds may be curved either from the beginning or later.

Variations in operational mechanics are numerous, and deciphering of the several steps may be difficult or impossible, yet it appears that different modes of growth should create distinctive minor folds or fracture systems as well as variations in contemporaneous sedimentary overstepping, any of which might be indicative of certain sequences of mechanic operations. Consideration of several possible operational sequences and deductions as to their consequences may lead to better genetic conclusions. The synthesis of folds should include, in addition to stress and kinematic analyses, the mechanical evolution. The concept of operational mechanics may be employed also in other kinds of deformation.

JOINTING ON THE COLORADO PLATEAU

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The principal joint sets of most of the Colorado Plateau have been mapped largely from air photos and compiled on a tectonic map at a scale of 1:500,000. Most of the joints are in Permian or Mesozoic rocks, but some are in rocks as old as Precambrian or as young as late Tertiary.

The distribution of sets and the spacing of joints within sets are irregular. Viewed regionally the joints of northwesterly trend are the most numerous followed by those of northeasterly trend. Several zones of east-west sets stand out in the regional pattern. Large areas are dominated by joints of only one trend, but elsewhere two or three sets may be about equally developed. Some persistent sets extend for more than 100 miles.

Little consistent relationship exists between the joint systems and the uplifts or other tectonic elements of the plateau. The major sets display considerable variation in their trends with respect to the elongation of the uplifts. Large irregular joint-system sectors form a mosaic across the plateau. In some places the boundaries between the sectors are fairly sharp, but elsewhere the boundaries are not clearly defined, and there is considerable interpenetration of certain sets of adjoining sectors.

The joints are clearly of several different ages and causes, but the predominant and persistent sets may be the result or aftermath of Laramide deformation.

DISTRIBUTION OF BROWNS PARK FORMATION IN EASTERN UINTA MOUNTAINS, NORTHEASTERN UTAH AND NORTHWESTERN COLORADO

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In its type area, northeastern Utah and northwestern Colorado, Browns Park formation (Miocene?) consists of interbedded tuff, tuffaceous sandstone, bentonitic clay, and conglomerate; it rests, according to W. H. Bradley, on the Bear Mountain surface which is 600 feet or more below the high-level Gilbert Peak surface on which rests Bishop conglomerate (Miocene?).

Rocks resembling and tentatively correlated with type Browns Park are far more widely distributed in the central and eastern Uinta Mountains than previously reported. White tuff and tuffaceous sandstone are found hundreds of feet below the Bear Mountain surface and down to water level of Green River in the Little Hole-Dutch John area. On the south flank of the Uinta Mountains in the Mosby Mountain-Diamond Mountain and Harpers Corner-Blue Mountain Plateau areas tuffaceous sandstone and interbedded conglomerate rest on remnants of a broad erosion surface that is probably correlative with the Gilbert Peak surface. Along the main divide west of Lodore Canyon, in the Pot Creek-Summit Valley area, and on Douglas Mountain to the east the Browns Park formation fills valleys in a maturely dissected terrane. The Browns Park formation probably once extended across the crest line of the Uinta Mountains as a continuous blanket.

These relations suggest (1) that the Green River in Little Hole-Dutch John area flows through an exhumed canyon, (2) that the initial course of the Green River across the Uinta Mountains was upon Browns Park formation, and (3) that the Green River through Lodore Canyon is superimposed.

SEDIMENTARY STRUCTURES IN THE BLOMIDON FORMATION, A TRIASSIC LAKE DEPOSIT, NOVA SCOTIA

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Sedimentary structures which are diagnostic of the lacustrine origin of the Blomidon formation include graded bedding, symmetrical ripple marks, and convolute lamination. A shallower-water facies containing current ripple marks, worm trails, oriented plant fragments, groove casts, raindrop imprints, and mudcracks is recognized in southwestern Nova Scotia and along the north shore of the Minas Basin. A deeper-water facies characterized by uniform bedding, thin lamination, and symmetrical ripple marks is recognized at Gerrish Mountain and the northern Annapolis-Cornwallis Valley. Both facies are characterized by graded bedding and convolute lamination. Structures in the shallower-water facies suggest deposition on a periodically uncovered shelf or delta plain.

The Wolfville formation, of fluviatile origin, underlies the Blomidon formation in southwestern Nova Scotia. The McKay Head basalt, an extrusive, separates Wolfville formation from Blomidon formation on the Minas Basin north shore. Directional current structures in both the Wolfville formation and the shallower-water facies of the Blomidon formation indicate northeastward flow in southwestern Nova Scotia and southwestward flow on the Minas Basin north shore. Damming of the earlier drainage by extrusion of McKay Head basalt probably formed the lake in which the Blomidon was deposited.

In combination, the above-mentioned structures proved valuable in recognizing the lacustrine origin of the Blomidon formation. Their use may be applicable to other areas.

STRATIGRAPHY OF THE TRIASSIC ROCKS OF NOVA SCOTIA

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Previous investigations in the Nova Scotia Triassic recognized the following stratigraphic units (descending order): Scots Bay formation, North Mountain basalt, Annapolis formation. The Annapolis formation was subdivided into a Blomidon shale member above and a Wolfville sandstone member below. An agglomerate, the Five Islands volcanics, was recognized between the Wolfville and Blomidon members on the north shore of the Minas Basin (an arm of the Bay of Fundy).

Recent stratigraphic study of the Wolfville and Blomidon members shows that the origin of each is different. The Wolfville is a red conglomeratic, coarse- to fine-grained sandstone of fluviatile origin, whereas the Blomidon consists of interbedded fine-grained sandstone, siltstone, and claystone of lacustrine origin. In the Annapolis-Cornwallis Valley, the upper part of the Wolfville interfingers with the lower part of the Blomidon. On the Minas Basin north shore, both the Wolfville and Blomidon interfinger from the base of the Blomidon upward to the overlying North Mountain basalt. It is recommended that the Wolfville and the Blomidon be raised to formational status.

Examination of the Five Islands volcanics shows that they are not pyroclastic but consist of basalt-siltstone boulder conglomerates at the base of the Blomidon formation. It overlies a heretofore unrecognized basalt flow from which the conglomerate was derived.

The Triassic formations of Nova Scotia are therefore as follows:

Annapolis-Cornwallis Valley	*Minas Basin North Shore*
Scots Bay formation	
North Mountain basalt	North Mountain basalt
Blomidon shale	Blomidon shale and Wolfville sandstone
	Unnamed basalt
Wolfville sandstone	Wolfville sandstone

ELKHORN MOUNTAINS VOLCANIC FIELD, WESTERN MONTANA

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Remnants of a thick plateaulike accumulation of calc-alkaline volcanic rocks of probable Late Cretaceous age—the Elkhorn Mountains volcanic rocks—are exposed in an area of about 3000 square miles around the Boulder batholith in the Elkhorn Mountains and Boulder Mountains, western Montana. The presence of similar rocks across the Jefferson River to the south, and near Wolf Creek to the north, suggests that the volcanic pile once covered as much as 10,000 square miles.

In places these rocks rest unconformably on Paleozoic and perhaps older rocks. Elsewhere they are gradational into underlying tuffaceous sedimentary rocks of Late Cretaceous age, and the contact is arbitrarily placed at the base of the lowest volcanic conglomerate, breccia, or flow.

The volcanic pile comprises three major units; maximum thickness of each exceeds 5000 feet. The lower unit consists predominantly of dacitic, andesitic, and basaltic fragmental rocks and autobrecciated lava flows. The middle unit is about half quartz latite in welded tuff sheets as much as 300 feet thick, interlayered with more calcic bedded pyroclastic rocks and autobrecciated lava flows; it is locally unconformable on the lower unit. The upper unit consists dominantly of reworked volcanic rocks and subordinately of fine-grained pyroclastic rocks. A thick succession of basalt flows near Elliston, Montana, may be equivalent to the upper part of this unit or may be younger.

The volcanic rocks were altered by and locally foundered in penecontemporaneous shallow-magma reservoirs. They were folded and faulted and later invaded and thermally metamorphosed by the Boulder batholith.

GRAHAMITE DIKES IN THE PITTSBURGH COAL, WASHINGTON COUNTY, PENNSYLVANIA

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Two vertical, solid hydrocarbon dikes have been encountered during mining of the Pittsburgh coal in northern Washington County, Pennsylvania. The parallel dikes, 35–50 feet apart, trend N. 56° W. for at least 7000 feet. Where examined, the northeastern dike measures 14–18 inches thick; the southwestern dike averages 14 inches.

Two distinct asphaltite varieties are noted. The predominant variety (type A) has a brilliant black luster, a vitreous texture, and a distinct conchoidal fracture. The second material (type B) has a dull black luster, a granular texture, and a hackly fracture. The dull variety was not found in contact with the coal. Both varieties are soluble in carbon disulfide; type B is more readily soluble than type A. Both are virtually insoluble in carbon tetrachloride. Specific gravity of type A is 1.14-1.15 as contrasted with 1.12–1.13 for type B. Both fuse with difficulty. The above tests and other analyses closely resemble those of grahamite; consequently both substances are presumed to be varieties of grahamite.

No interaction is apparent between the grahamite and coal macerals. Cell lumina of fusinite and semifusinite near the veins are filled with the hydrocarbon. Observations suggest that the hydrocarbon was rather viscous when intruded; no evidence of thermal alteration of the coal was found. Measurement of displaced coal particles indicates that the coal was bituminous in rank at the time of intrusion. A petroliferous origin of the grahamite is suggested.

STANNITE SERIES

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Before studying the order–disorder relations at elevated temperatures of a group of ZnS-lattice-type sulfide minerals, it was necessary to reinvestigate the stannite problem. Stannite specimens from various mines in Bolivia, Wales, Canada, Tasmania, United States, and Bohemia were studied using the Nonius-Guinier powder and the Buerger Precession X-ray techniques.

The samples were crushed, cleaned with bromoform, and then magnetically separated. From most localities two types of stannite were obtained. Good separation was obtained, because tetragonal stannite is more magnetic than the recently described isostannite.

Single-crystal X-ray study of the isostannite revealed that it has a pseudoisometric symmetry and is actually tetragonal with $2a_0 = c_0$ and the space group $I\bar{4}2m$. The value of c_0 ranges between 10.83 and 10.90 A.

The normal tetragonal stannite also shows a range of lattice parameters. The plot of the axial ratio of these stannites against the Zn content (excluding Ag-rich varieties) reveals that c_0/a_0 increases as the Zn content increases, and those varieties having $2a_0 = c_0$ have an atomic ratio of Fe to Zn near 1:1.

POLLEN AND SPORE CONTENT OF MODERN ORGANIC SEDIMENTS FROM FLORIDA COMPARED TO THE MICROFLORAL ASSEMBLAGES CHARACTERIZING LITHOTYPES OF TERTIARY COAL SEAMS FROM GERMANY AND SOUTH DAKOTA

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Intensive palynological investigations of brown coals from the Lower Rhine Basin in Germany have made it possible to trace changes of vegetation within a seam that reaches a thickness of 300

feet. Nine different pollen florules, representing swamp types, were found by P. W. Thomson. Similar successions were recognized later in many other lignites, and differentiation of swamp types was successfully applied to bituminous coal. E. Hofmann inferred the presence of a mangrove swamp type in the Flysch sediments of the Alps.

On the basis of quantitative spore analyses as well as tissue-fragment tallies and ash analyses, the lignites of South Dakota can also be subdiviced into various zones (lithotypes) representing different swamp types. Some of them are similar to those found in Germany.

Palynological research in the modern swamps of Florida indicates that Thomson's "forest swamp types with many pine or palm pollen" represent the bordering zones or drier ridges of swamp areas. Cypress heads and dense cypress forests may be comparable with his "sequoia forest swamp type." The sediments of sawgrass swamps of the Everglades cannot, in most cases, be compared with the fossil "everglade swamp type" of the literature. The pollen content of the modern mangrove swamp in Florida is different both in species composition and density from that of the brown coals of Germany. These peats are extremely poor in pollen content and contain great quantities of sand particles and remnants of marine micro-organisms.

SEDIMENTARY CYCLES

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Two basic discrete polar elements build all sedimentary cycles, *i.e.*, series that repeat themselves: (1) influx cycles, where effective utilization of energy decreases asymptotically toward the end of a sedimentary episode, and (2) fill-in cycles where the opposite is true. In clastic rocks the simplest examples respectively are upright vs. inverted graded stratification. A chemical crystallodepositional fill-in cycle is the limestone-evaporite sequence. Cyclicity develops laterally as well as vertically, from wave layerlets to regressive complexes.

Basic combinations are simple influx; simple fill-in: carbonates; fill-in followed by influx: cyclothems; and influx followed by fill-in (playas).

A cycle shows a basic sovereign lithologic sequence and several satellitic rock types potentially present at determined positions.

Cyclicity is caused first by primary or immediate sedimentary factors, rarely accidental but generally systematic, produced by interplay of phases within systems of sedimentation for short distances.

Second come the ultimate factors, either tectonic subblocs, 15–35 miles across, with oscillatory facial changes, or subregional tectonic blocs controlling major regressive-transgressive complexes. Climatic and eustatic factors are less potent. Fill-in cycles depend entirely on basinal tectonics; influx cycles are complicated.

Factor interaction produces certain polar-modal mass resultants, namely the classical cyclicity types; coal cyclothems; primary-secondary dolomite coupled pairs; banded carbonates; sandstone-shale complexes; red beds.

Finally cyclicity is treated first empirically, then analytically, and last theoretically through the four basic tectonic types, the five sedimentary rock series, and the six major environments of deposition groups.

SYSTEM Ni-S

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The system Ni-S has been systematically studied from 200° to 1030°C. by evacuated sealed silica-tube experiments and differential thermal analyses. Compounds in the system are Ni_3S_2 (and a high-temperature, nonquenchable $Ni_{3\pm x}S_2$ phase), Ni_7S_6, $Ni_{1-x}S$, Ni_3S_4, and NiS_2. Of these, heazlewoodite

(Ni_3S_2), millerite ($Ni_{1-x}S$), polydymite (Ni_3S_4), and vaesite (NiS_2) are minerals. The hexagonal heazlewoodite, which does not form measurable amounts of solid solution on either the Ni or S side, on heating inverts to an apparently tetragonal structure at 550°C. This high form has a wide field of stability, from 23.5 to 30.5 weight per cent S at 600°C. Its chemical formula may be written $Ni_{3\pm x}S_2$, and it melts incongruently at 806 ± 3°C. The Ni_7S_6 phase inverts at 399 ± 2°C. and decomposes to $Ni_{3\pm x}S_2$ + NiS at 573 ± 2°C. $Ni_{1-x}S$ occurs in two crystallographic forms. The low-temperature form, millerite, is rhombohedral, and the high form has the hexagonal NiAs structure. NiS inverts at 379 ± 3°C.; $Ni_{1-x}S$ with maximum Ni deficiency inverts at 280 ± 5°C. The $Ni_{1-x}S$-NiS_2 solvus was determined to 982 ± 3°C., the eutectic temperature between these phases. $Ni_{1-x}S$ in equilibrium with NiS_2 at 982 ± 3°C. contains 61.4 weight per cent Ni and at 745 ± 3°C. 62.5 weight per cent Ni. Stoichiometric NiS melts at 807 ± 3°C., and $Ni_{1-x}S$ with 62.3 weight per cent Ni melts at 992 ± 3°C.

The cubic Ni_3S_4 phase at 303 ± 3°C. decomposes to $Ni_{1-x}S$ + NiS_2. The cubic NiS_2 (vaesite) phase melts congruently at 1010 ± 5°C. Vaesite composition does not vary measurably and is within the limits of $NiS_{2.000\pm0.005}$ even at 900°C.

GEOLOGICAL TIME SCALE

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A revision of the absolute geologic time scale from the Cambrian until the present is suggested as a result of new isotopic age measurements on stratigraphically related rocks obtained at Lamont Geological Observatory and other laboratories. Some of the critical localities are (Cambrian) Wichita Mountains, Oklahoma; Vastergotland, Sweden; (Devonian) Shap, England; Maine; Greenland; (Carboniferous) Magnitogorsk, U.S.S.R., Vosges, Schwarzwald, and Massif Central; (Permian) Dartmoor, England; Oslo, Norway; Solikamsk, U.S.S.R.; (Triassic) Palisades, New Jersey; (Jurassic) Kelasury, U.S.S.R.; Sierra Nevada, California; (Cretaceous) Blairmore, Alberta; Coast Range, California; (Paleocene) Central City, Colorado; (Eocene) Caucasus, U.S.S.R. These results indicate the beginning of the major periods to be as follows: Ordovician 490 m.y., Silurian 430 m.y., Devonian 410 m.y., Mississippian 355 m.y., Pennsylvanian 330 m.y., Permian 275 m.y., Triassic 220 m.y., Jurassic 180 m.y., Cretaceous 135 m.y., and Tertiary 70 m.y. These dates give a scale about 15 per cent longer than that of Holmes (1947) before the Cretaceous. The relationship between the scales is not systematic but is a result of large increases in the estimated lengths of the Jurassic, Permian, and Carboniferous. The writer suggests that the base of the absolute paleontological scale be taken as the Lower-Middle Cambrian boundary (540 m.y.) because of the uncertainty in the definition of the base of the Cambrian. The further refinement of the geological time scale is primarily dependent on the discovery of new localities that have minerals suitable for accurate age determinations that are stratigraphically defined.

ERRATICS THROUGH LETDOWN, WESTERN ALBERTA, CANADA

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Field geologists working in sections containing rocks of widely divergent erosion resistance are well acquainted with letdown, the natural lowering of slabs and fragments of rock by erosion of more vulnerable underlying rock. Where letdown is of such magnitude that the once higher rock lies upon a totally different terrain the letdown fragments are erratics. The largest letdown erratics known to the writer are four slabs of Mississippian(?) Rundle limestone lying, with thousands of smaller fragments, on Folding Mountain in the Foothills belt of western Alberta, about 200 miles west of Edmonton. The largest of these slabs measures 30 by 25 by 15 feet approximately; the four slabs

must total about 2700 tons in weight. Folding Mountain is made up of sandstones, shales, conglomerates, and coal beds of Kootenai (Early Cretaceous) age. The Rundle limestone occurs in place in the mountains about 3 miles to the southwest, across the trace of the Rocky Mountain overthrust fault plane. The Paleozoic formations once overrode the Cretaceous rocks in what is now the Foothills belt, as well as in the present mountain area, and the loose limestones on Folding Mountain and elsewhere in the Foothills were let down from that thrust sheet by the more rapid erosion of less resistant rocks. Some of these Paleozoic residua have been let down many hundreds of feet.

There is no evidence to support any alternate method of transport such as landslides, glaciers, or ice rafting.

STRATIGRAPHY AND PALEONTOLOGY OF THE TIN MOUNTAIN LIMESTONE AND PERDIDO FORMATION, QUARTZ SPRING AREA, DEATH VALLEY NATIONAL MONUMENT, INYO COUNTY, CALIFORNIA

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The upper Devonian and Mississippian sequence of the Quartz Spring area forms part of deposits pertaining to the Miogeosynclinal Carbonate and Detrital Province of the Mississippian system in the Great Basin. Deposition of these rocks in the Quartz Spring area began with accumulation of a newly named sandstone member of the Lost Burro formation. This Upper Devonian unit, consisting of quartzite and interbedded sandy dolomite and limestone, contains a fauna characterized by *Cyrtospirifer* cf. *C. monticola* Haynes. Thereafter the Early Mississippian Tin Mountain limestone, consisting of a lower, argillaceous limestone member of lagoonal or mudflat origin succeeded by an upper, crinoidal limestone member, was deposited on an offshore bar or bank. The Tin Mountain limestone fauna correlates with the "Madison fauna" of Western North America and includes new species of *Clisiophyllum*,? *Ekvasophyllum*, *Enygmophyllum*, *Meniscophyllum*, and *Rylstonia*. The species of *Enygmophyllum* and *Rylstonia* are the first representatives of these genera to be described in North America. The Late Mississippian Perdido formation consists of a lower limestone member and an upper siltstone member recording a progressive decrease in marine sedimentation during Late Mississippian time. Fossils are generally rare in the Perdido formation, but several thin limestone layers near the top are abundantly fossiliferous. One of these is a goniatite coquina formed chiefly of specimens of *Cravenoceras hesperium* Miller and Furnish. The overlying Rest Spring shale, questionably Mississippian or Pennsylvanian, lithologically resembles the Mississippian Chainman shale member of the White Pine shale.

CROSS SECTION OF A SMALL FLOOD PLAIN IN THE APPALACHIAN PLATEAU

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Beaverdam Run, in the eastern Allegheny Plateau of Pennsylvania, drains an area of 42 square miles whose average relief is 240 feet. The cross section studied is at a constriction in the valley where the flood plain is about 1250 feet wide, and the stream is at the western edge. Channel fill, lag gravels, lateral accretion, vertical accretion, and colluvium are present. The bedrock floor of the alluvial valley has a local relief of about 1 foot and is lowest on the east. The bedrock beneath the side of the flood plain slopes at about 22°.

A core trench gives continuous exposures to bedrock in the easternmost edge of the valley, and bore holes to bedrock give information on the rest of the cross section. The colluvium is 40 feet thick at the eastern edge and extends as a wedge 500 feet westward across the flood plain. Lateral

accretion having a median grain size of 0.145 mm and a sorting coefficient of 1.67 directly overlies the bedrock floor in the trench. It is about 6 feet thick and shows no stratification. Vertical accretion, about 2 feet thick, overlies the lateral accretion and is comprised of about 50 per cent clay and 50 per cent silt. Lenses of vertical accretion occur within the overlying colluvial wedge. Channel fill and lag gravels occur throughout the cross section.

The stream is about 4 feet deep at bankfull stage and is about 20 feet above the bedrock floor. It is therefore probably aggrading.

WISCONSIN GLACIAL FEATURES IN EXTREME EASTERN SOUTH DAKOTA

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A detailed investigation of the Wisconsin drift in the middle portion of the Prairie Hills in extreme eastern South Dakota was made in conjunction with the field mapping program of the State Geological Survey of South Dakota in 1957 and 1958. Although the age of various Wisconsin drift sheets in this region has not been determined by the radiocarbon method, the presence of Iowan, Tazewell, and Cary drifts is indicated by the topographic expression and physical properties.

The Iowan drift consists of brown and bluish-gray clayey till. It attains a thickness of more than 100 feet as shown by boring. A short span of Tazewell glaciation in this region is indicated by the presence of drift that can be differentiated from the Iowan mainly by the stratigraphic sequence and lithologic character.

Topographic and lithologic similarities suggest correlation of Flint's Cary moraine of the James lobe with the Altamount moraine of the Des Moines lobe. Ruhe, Rubin, and Scholtes (1958), however, consider that the Altamount moraine represents a recessional event following retreat from the Bemis moraine, on the basis of radiocarbon dates in Iowa. A further study concerning the radiocarbon age of the Altamount moraine in eastern South Dakota is required. Recessional ground moraine is commonly associated with the Cary end moraine of the James lobe. Petrographic study of this drift unit indicates that it can be correlated regionally on the basis of detrital mineral assemblages.

GEOLOGICAL ASPECTS OF THE QUESTION OF CONSTANCY OF RATE OF COSMIC RADIATION

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Carbon-14 dates for substages of the Wisconsin have quickened the tempo for the work of the great ice sheets. Striking inconsistencies of dates are not of concern in the present discussion; of concern are those dates which have the appearance of integrity, and what they demand in rate of geological accomplishment and of events that transpired, as in the case of glacial advance and retreat of the ice front.

The late and respected Horberg called attention to these matters in his paper, *Radiocarbon dates and Pleistocene chronological problems in the Mississippi Valley region*. Antevs, an intrepid field student of varves and rational philosopher of glacial geology, has protested C-14 dating from the standpoint of its inconsistency with dates derived from varve counts. The writer also feels that the history of the Tazewell subage demands more time than C-14 dates permit.

This paper will deal, in whole or in part, with geological facts and inferences. Obviously the latter may or may not be subject to question. The nature of the Glacial epoch and its causes are pertinent aspects of the subject. The matter should have the rational consideration of the scientist, regardless of his immediate affiliations, if his work is in a field related to the subject.

MEASUREMENT OF PORE-SIZE DISTRIBUTION IN SOME HYDROTHERMALLY ALTERED WALL ROCKS

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Pore sizes and their distribution were determined for a series of altered andesites sampled perpendicular to a leptothermal Pb-Zn-Ag vein in the Topia Mining District, Durango, Mexico. The alteration zone paralleling the vein consists of a wide propylitized band and a narrower superimposed quartz-sericite band adjacent to the vein.

The data were obtained by use of a mercury capillary apparatus. The pore-entry size is determined by measuring the pressure applied to a nonwetting fluid (mercury) to bring it in equilibrium with the capillary pressure of the pore being investigated. By measuring the volume of mercury injected at given increments of pressure ranging from 0 to 2000 psi, the pore-entry size range and the portion of the void volume they occupy are determined.

Pore-size distribution curves show that in fresh and altered andesites the greatest number of pores have a pore-entry radius of .1 micron or less. With increasing alteration intensity, greater numbers of very small pores are created. As the vein is approached there is a corresponding increase in the number of pores .1 micron and smaller in radius. Larger pores also form, but they are relatively few in number. The study demonstrates that the alteration process creates an environment characterized by a large amount of surface area available as potentional reaction sites.

CHEMISTRY AND ORIGIN OF IRON FORMATIONS

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The Fe content of 15 comparatively unaltered iron formations, Keewatin (>2.6 b.y.) to Jurassic in age, ranges from 25.4 to 35.0 weight per cent as is indicated in published analyses. The other major constituents are SiO_2, CaO, MgO, and Co_2. Silica and carbonate contents vary inversely.

Cherty iron formations of great thickness and areal extent are restricted to the Precambrian. Geologic processes operative since the Precambrian have effectively separated iron and silica and have resulted in extensive deposits of chert (*e. g.*, Caballos novaculite) and of carbonate iron ores (*e. g.* Birmingham, Alabama, East Texas).

Differences between Precambrian and younger iron formations are attributed to secular changes in the atmosphere. In Precambrian times weathering akin to laterization retained aluminum, titanium, and phosphorus in the regolith, but unlike recent laterization processes, the Precambrian processes also supplied iron and silica, alkaline earths, and alkalies to the ground waters.

A relative deficiency in oxygen in the Precambrian atmosphere promoted the solution and transportation of iron as the bicarbonate. In the lithosphere Fe and Ca are present in mole proportions of about 1:1. The writers postulate that siderite and roughly equal amounts of calcite were deposited on a relatively stable shelf (miogeosyncline). The primary carbonates were replaced in varying degree by silica. Iron silicates and iron oxides were developed through diagenesis and low-grade metamorphism.

The graphitic slates commonly associated with Precambrian iron formations indicate that primitive life was abundant.

ORBICULAR ROCKS OF THE LONESOME MOUNTAIN AREA, BEARTOOTH MOUNTAINS, MONTANA AND WYOMING

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The Lonesome Mountain area, Beartooth Mountains, Montana and Wyoming, includes large outcrops of orbicular gneiss in a terrain of amphibolites, migmatites, and granitic gneisses. The

orbicules have cores of plagioclase, biotite, or hornblende-biotite, surrounded by alternating plagioclase-rich and biotite- or hornblende-rich shells. Radially oriented biotite, pseudomorphous after hornblende, and radial plagioclase are common in the cores. Tangentially oriented biotite occurs in the biotite-rich shells. Field and laboratory evidence indicates that orbicules form as an abnormal byproduct of granitization of amphibolites. Orbicule formation involves feldspathization without complementary quartz enrichment.

Metamorphic orbicules and Liesegang phenomena are compared. Both result from diffusion processes that produce discontinuous, periodic precipitation.

Dimensional analyses of shell spacings are significant in determining the mechanism of orbicule formation. Rhythmically banded phenomena fall into two groups according to spacing of their bands: (1) spacing in exponential progression—metamorphic orbicules, spherulites, Liesegang rings, some agates; (2) spacing in arithmetic progression—igneous orbicules, concretions, oölites, oscillatory-zoned plagioclase, stalactites, varved argillites.

Objects of group 1 form by internally controlled rhythmic processes, which are always disequilibrium phenomena. Those of group 2 form by externally controlled rhythmic processes and may be equilibrium or disequilibrium phenomena. Spacing of bands indicates which type of process was operative and the attainment of equilibrium. Orbicules of the Lonesome Mountain area have shells exponentially spaced and result from an internally controlled rhythmic diffusion process. Series of orbicular rocks show progressive Na enrichment of plagioclase and changes from hornblende to biotite, indicating outward diffusion of Ca, Fe, and Mg.

HIGH HAFNIUM ZIRCON FROM NORWAY

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High hafnium zircons from Iveland, Norway, have been found to contain 22–24 per cent HfO_2. The Hf/Zr ratio is about 0.6. The zircons occur as two small cauliflower-shaped clusters protruding from a crystal of thortveitite (scandium silicate). The zircon clusters have specific gravities of 5.1 and 4.8, are not metamict, and do not contain any thorium or uranium (if present, less than 100 ppm). They have only traces of beryllium (*ca.* 100 ppm) and small amounts (less than 4 per cent) of the yttrium subgroup of the rare earths. X-ray-diffraction patterns give slightly diffuse lines, but the material is still crystalline.

These are believed to be the first true zircons (as distinct from the imperfectly known varieties such as alvite, cyrtolite, malacon) reported to contain high hafnium.

The presence of hafnium and zirconium within the structure of three specimens of Norwegian thortveitite has been verified. Although the content of these elements has not been determined quantitatively, the results correspond qualitatively with those reported in the literature.

PALEOZOIC OUTLIERS WITHIN THE CANADIAN SHIELD*

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The present distribution of Paleozoic outliers in the Canadian Shield is chiefly due to post-Devonian, pre-Pleistocene erosional processes. Pleistocene processes have probably had only minor effect.

At present about 20 outliers are known; an additional 10 localities exhibit loose material "far removed" from the nearest known Paleozoic rocks. For the most part they constitute small areas of 1 square mile or less and only a thin section of sedimentary rocks. Their age ranges from Cambrian on the Strait of Belle Isle, Ordovician at Nicholson Lake, N.W.T., and Silurian at Lake Timiskaming, Ontario, to possibly Devonian. In most cases preservation is not dependent upon faulting.

* Published with the permission of the Director, Geological Survey of Canada, Ottawa

The list of known outlier localities is increasing rapidly. The existence of these little publicized outliers suggests that a re-evaluation of some of our paleogeographic concepts is in order. The writer suggests that Paleozoic formations extended far beyond the present main outcrop areas of these systems. The probable extent of these seas is most apparent when the outliers are plotted on a small-scale geological map of Canada. The resultant pattern indicates that: (1) at least broad southern marginal areas of the Canadian Shield were covered by continental seas in Ordovician, Silurian, and possibly Devonian time; and (2) straits or wide arms must have extended across the Shield to connect with seas on its Arctic margin. Possibly most of the Canadian Shield, at one time or another, was masked by Paleozoic cover.

DIELECTRIC CHARACTERISTICS OF SELECTED LAYER SILICATES

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The dielectric properties of clay minerals and related layer silicates have been measured over a frequency range of 30 to $7(10^4)$ cycles per second and a temperature range of about 25° to 300°C. The dielectric loss was found to be fairly independent of frequency for all the materials used, whereas the dielectric constant was found to decrease monotonously with frequency. Maxima and minima were observed in both the dielectric constant and the dielectric loss as a function of temperature. The frequency dependence of the imaginary part of the complex dielectric constant is related to the degree of order in the crystalline phase.

In general, the dielectric data are consistent with a multiple relaxator model based on a distribution of potential wells.

CRYSTAL STRUCTURES OF THE ISOSTRUCTURAL MINERALS LAZULITE, SCORZALITE, AND BARBOSALITE

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Lazulite, $MgAl_2(PO_4)_2(OH)_2$, and scorzalite, $FeAl_2(PO_4)_2(OH)_2$, form a complete isomorphous series. Barbosalite, $FeFe_2(PO_4)_2(OH)_2$, the ferric analog of scorzalite, is not known to form solid solutions with the lazulite-scorzalite pair. The minerals are monoclinic, $P2_1/c$, Z = 2, with cell constants as follows:

	Lazulite (Fe″:Mg=0.11:0.89)	*Scorzalite* (Fe″:Mg=0.77:0.23)	*Barbosalite* (Fe″=1.00)
a	7.16 Å	7.15	7.25
b	7.26	7.31	7.46
c	7.24	7.25	7.49
β	120°40′	120°35′	120°15′

The structure common to the three minerals consists of the packing together of metal ion-oxygen octahedra and phosphate tetrahedra. The phosphorus is bonded to four nonequivalent oxygens. The proton present is assigned to the fifth independent oxygen. A magnesium-oxygen octahedron and two aluminum-oxygen octahedra share faces to form triple groups. These triple groups are linked together through corner-shared hydroxyls and through corner-shared oxygens of the phosphate groups. Each corner of a tetrahedral phosphate group is shared with a corner of an octahedral group in such a way as to tie the octahedral groups together laterally into sheets, and the sheets together into a three-dimensional edifice.

ISOTOPIC AGES IN THE AREA OF THE CITY OF NEW YORK

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Potassium-argon and rubidium-strontium age measurements have been made on mica from the igneous and metamorphic rocks in the Manhattan Prong (City of New York and Westchester County) and the New Jersey-New York Highlands. The agreement of 12 K-A ages from the New York group gives strong evidence that the time of latest metamorphism in the Manhattan Prong occurred about 365 m. y. ago. A prior metamorphic history in the prong is further indicated by relict ages ranging as high as 440 m. y. In the New Jersey Highlands at least 10 miles from the area affected by the 365 m. y. event, mica ages of 800–900 m. y. are obtained. Discordant U-Pb ages on uraninite and monazite suggest a Highlands minimum age of 900 m. y.

East of the Hudson River the A/K and Sr/Rb ratios in the Highlands mica have been altered by the later event, producing apparent ages between 360 and 800 m. y. In a transition zone 10-15 miles wide within the Highlands complex, large variations in apparent age between closely spaced samples (1–2 miles apart) indicate that the degree of recrystallization was strongly dependent upon local structure. The eastward trend from unrecrystallized to totally recrystallized Highlands mica, as reflected in the isotopic ages, is the counterpart of Balk's (1936) observation of progressive metamorphism to the east of the Paleozoic rocks in adjacent Dutchess County. Isolated age measurements in areas of complex metamorphic history may be very misleading and may not refer to the time of any particular geologic event.

URANIUM AND PHOSPHATE IN THE GREEN RIVER FORMATION OF WYOMING

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Notably high concentrations of syngenetic uranium and phosphorus characterize at least three beds in the lower 100 feet of the partially lacustrine Wilkins Peak member of the Green River formation (Eocene) in southwestern Wyoming. Uranium varies with phosphorus; uranium replaces calcium ions in carbonate fluorapatite.

The stratigraphically lowest, thickest (as much as 3 feet), richest, and most widespread zone, a dense gray "marlstone", has been identified along an outcrop distance of more than 100 miles. The richest 3–6 inches along 40 outcrop miles (16 sections studied) averages 0.060% eU, 0.055% U, 8.1% P_2O_5; maximum 0.15% U, 18.2% P_2O_5. Sixty feet higher 1 foot of a green blocky "claystone" along 16 outcrop miles (5 sections studied) averages 0.012% eU, 0.009% U, 3.4% P_2O_5; maximum 0.012% U, 4.8% P_2O_5. Forty feet higher a 3-inch brown "oil shale" along 18 outcrop miles (5 sections studied) averages 0.013% eU, 0.012% U, 8.1% P_2O_5; maximum 0.019% U, 12.9% P_2O_5.

Chemical and X-ray study of one apparently typical "marlstone" shows ⅓ apatite, ⅛ dolomite, ¼ zeolite (analcite?), and the remainder insoluble (detrital?) minerals.

Only a very small part, stratigraphically and areally, of the Green River formation has been investigated. Probably many other beds with abnormally high concentrations of U-P_2O_5 exist, in Utah and Colorado, as well as Wyoming. Possible sources of U and P_2O_5 are volcanic ash in the Green River formation and phosphatic Permian rocks eroded from the rising Uinta Mountains during middle Eocene time.

GEOPHYSICAL INVESTIGATIONS IN THE SUBMERGED ARGENTINE COASTAL PLAIN. PART I: CONTINENTAL SHELF, CONTINENTAL SLOPE, AND CONTINENTAL RISE BETWEEN BUENOS AIRES AND THE VALDES PENINSULA

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During the winters of 1957, 1958, and 1959, seismic-refraction measurements were conducted in the submerged Argentine coastal plain and adjacent deeps by the research vessel VEMA of Columbia

University and ships of the Argentine hydrographic service. The results of 61 of the seismic stations are reported here.

The sequence of major seismic horizons is similar to that reported for the submerged coastal plain of the eastern United States. Important structural features are filled depressions in the crystalline rock floor of the continental shelf. The most prominent of these is an elongated asymmetrical basin west and southwest of Bahia Blanca in which a total thickness of 6.5 km of sediment was found. A second depression, perhaps part of the one near Bahia Blanca, was found south and southeast of the River Plata estuary.

A 1-km-interval contour map of the basement rock surface and seismic sections are presented.

PHASE EQUILIBRIA IN THE SYSTEM IRON OXIDE-TITANIUM OXIDE AT LOW-OXYGEN PRESSURES

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The quenching technique has been used to study phase relations in the liquidus temperature region of the system iron oxide-titanium oxide at low oxygen pressures. The control of oxidation states in condensed phases was achieved in some cases by containing the samples in iron crucibles and making runs in a nitrogen atmosphere and in other cases by using an iron-iron oxide buffer. Compositions of liquids obtained under both these experimental conditions do not fall along the join FeO-TiO_2 but rather along a curve crossing this join.

The following crystalline phases exist in stable equilibrium with liquids in the system: wüstite ulvospinel, ilmenite, pseudobrookite, rutile. When projected onto the join FeO-TiO_2 for purposes of simplified illustration, the diagram has the appearance of a binary system, with "invariant points" characterized by the following phase assemblages: 1310°C.: Wüstite, ulvospinel, liquid; 1366°C.: Ulvospinel, ilmenite, liquid; 1390°C.: Ilmenite, pseudobrookite, liquid; 1430°C.: Pseudobrookite, ilmenite, liquid. The "melting points" of ulvospinel, ilmenite, and pseudobrookite under the experimental conditions used in the present investigation are 1395°, 1397°, and 1494°C., respectively.

SILURIAN OF PICTOU COUNTY, NOVA SCOTIA

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The early Paleozoic is represented in Pictou County by fossiliferous sedimentary rocks of Silurian and Devonian age and by older volcanic and nonfossiliferous low-grade metamorphic rocks.

In the north is a syncline plunging W.-SW. The stratigraphy of the fossiliferous rocks in this structure is similar to that at Arisaig 20 miles northeast. The highest beds present belong to the Knoydart formation of Devonian age. These pass transitionally and conformably into the Stonehouse and Moydart formations beneath. The remainder of the Arisaig series of Silurian age is also represented, with the exception of the black shale member at the base of the Ross Brook formation. Conformably beneath lies a series of volcanic rocks and derived sedimentary rocks which are the counterpart of the Arisaig volcanic rocks and the Malignant Cove formation.

Five miles to the south a different Silurian stratigraphy is present. The highest beds are predominantly green, fossiliferous sandstones of the Stonehouse formation. Beneath these are dark-bluish-gray shales, slates, and minor quartzites that pass transitionally into a series of quartzites and minor mudstones at the base of which lies 2 feet of conglomerate. This is underlain by banded shales and slates grading into tuffaceous sandstone underneath.

The Silurian of Arisaig and northern Pictou County displays a marine shelly facies grading into Devonian red beds. In the Annapolis Valley 120 miles southwest the upper Silurian exhibits a graptolite facies and the Devonian a marine shelly facies.

STRESS-OPTICAL STUDY OF SYNTHETIC RUBY

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A pink ruby, in the form of a rectangular parallelopiped, was mounted in a crystal-compressing device, and pressure was applied parallel to its c-axis. The piezobirefringence constant (q_{3333}-q_{1133}) was determined by measuring the shift of retardation bands with increasing stress. Values of this constant range from 5.00×10^{-14} cm²/dyne at 470 mμ to 7.16×10^{-14} cm²/dyne at 660 mμ. The dispersion of the constant with respect to wave length is linear.

Measurements of biabsorption ($k_\epsilon - k_\omega$) were made at 10-mμ intervals in the spectral region 530 mμ–620 mμ. Pressures used were: (1) 0 g/cm², (2) 570,543 g/cm², (3) 703,660 g/cm², and (4) 1,017,102 g/cm². The data are summarized in the following table:

λ(mμ)	$k_\epsilon - k_\omega$			
	0 g/cm²	570,543 g/cm²	703,660 g/cm²	1,017,102 g/cm²
530	-5.86×10^{-6}	-6.03×10^{-6}	-6.92×10^{-6}	-7.93×10^{-6}
540	−7.31	−7.61	−8.22	−9.03
550	−8.76	−9.02	−9.64	−9.86
560	−9.80	−10.33	−10.51	−10.82
570	−9.31	−10.44	−11.03	−11.36
580	−6.91	−7.60	−8.58	−9.36
590	−5.11	−5.58	−6.04	−6.65
600	−3.10	−3.58	−4.15	−4.44
610	−1.94	−2.52	−3.25	−3.49
620	−1.13	−2.07	−2.71	−3.01

The data indicate a slight shift in the position of the biabsorption peak. At the highest stress, this peak is shifted about 3–5 mμ toward the longer wave lengths.

HYDROFLUORIC-ACID METHOD OF DISAGGREGATING SANDSTONES

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A new method has been developed for disaggregating sandstones by acid treatment. Attempts to disaggregate samples from the New York Upper Devonian Catskill facies using established laboratory methods were, at best, partially successful. A new method utilizing hydrofluoric acid as a disaggregating agent gave favorable, uniform results.

Rock fragments are placed in a plastic basket, which in turn is placed in a plastic tray; HF (concentration 49.2% HF) is poured over the fragments. After 20 minutes, 10 per cent of the fragmentr are disaggregated. The individual mineral grains are recovered from the bottom of the tray, washed, and dried. The heavy-mineral fraction may then be separated and mounted.

In order to determine the destructiveness of HF, weighed samples of known minerals were treated with HF for 22 minutes, washed, dried, and weighed. The per cent weight loss was calculated. Since each mineral was treated separately in HF, and each mineral grain, therefore, had the same specific gravity, the weight loss can be thought of as equal to the volume loss. Using the relationship $d_n = \sqrt[3]{1.92\ V}$, the per cent decrease in the diameter of a nominal sphere of each mineral grain was calculated. Garnet, rutile, zircon, and staurolite had less than 2 per cent loss in nominal diameter; chlorite,

spinel, tourmaline, kyanite, and apatite had less than 5 per cent; epidote and sphene had less than 14%. No change in optical properties was noted except for sphene, which suffered bleaching and a slight change in pleochroism.

STRATIGRAPHIC USE OF PARTICULATES IN POLAR ICE CAPS

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A stratigraphy based on particulates in the range of 0.6 μ–100 μ has been established in the deep ice cores from Byrd Station, Antarctica. Marked changes were found in the particle-size distribution of various stratigraphic zones. This is related to the particulate content of the summer and winter precipitation.

The utilization of a recently developed electronic "sieve" for blood-cell counting has provided a rapid method of particle sizing and counting in the 0.5 μ–500 μ range. By this technique a melted firn sample diluted by an electrically conductive liquid is drawn through a small aperture having immersed electrodes at either side. As each particle passes through the aperture, electrolyte is displaced, momentarily changing the resistance. The resultant series of pulses is proportional to the volume of the particles. These voltage pulses are electronically amplified, scaled, and counted. High particle counts commonly in the tens of thousands and the reproducibility of the counts provide statistical data.

The particulate content of the firn was separated by filtering the melted samples through membranes with retentions of 0.45 μ. Zones of volcanic ash and cosmic dust were investigated with the optical and electron microscopes and by spectrographic techniques.

These techniques are being evaluated in various Antarctic environments as an aid in determining the annual firn accumulation at the surface and at depth.

APPLICATION OF THE PHOTOMETER METHOD IN DETERMINING THE CRYSTALLOGRAPHIC FABRIC OF QUARTZ IN METAMORPHIC QUARTZITES

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A new photometric technique previously applied to an essentially two-dimensional fabric study of quartzose sandstones has been tested in a three-dimensional fabric analysis of metamorphic quartzites.

The technique thus far introduced into the literature consists of "measuring by means of an attached photometer the variation in the intensity of monochromatic light passed through a standard thin section of sandstone on the stage of a petrographic microscope with gypsum plate inserted and nicols crossed during a 360° rotation of the stage. Minimum intensity of light occurs when the trend of the optic axes of the quartz grains lies parallel with the slow direction of vibration of light in the gypsum plate."

The extension of this technique, proposed here, is that the direction in space of a preferred optic-axis orientation of quartz in a metamorphic quartzite that is either linear or planar may be determined by examining photometrically three mutally perpendicular thin sections. While these two limiting cases are considered susceptible of analysis, it is recognized that a fabric characterized by a point maximum in a girdle or a more complicated fabric cannot be exactly determined.

The Phantom Canyon quartzite of Algonkian age from the vicinity of Canon City, Colorado, has been studied in some detail by this method. Precambrian quartzites of the Picuris Range in New Mexico have also been studied. All these samples showed evidence of a dominantly linear orientation.

TERRAIN STUDY AND MAP OF THE SURFACE OF THE MOON

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The United States Geological Survey and the Army Map Service are preparing a joint terrain study and map of the surface of the moon. Observatories have co-operated by providing lunar photographs, which have been matched to obtain libration pairs for stereoscopic study. The Map Service is preparing a map at a scale of 1:5,000,000 on a modified stereographic projection. Elevations will be shown by form lines, and the interval will be dependent upon the precision of measurement. A second map, probably requiring several years to prepare, is contemplated at a scale of 1:1,000,000. The Geological Survey concurrently is preparing a terrain study describing surface features, including slopes. The study will include interpretations of the constituents and texture of the moon's surface and the likelihood of underground openings and caverns. The joint program is planned for use in the selection of landing sites on the moon, and in the designing of telemetering instruments and a lunar surface vehicle.

VARIATION IN PEBBLE LITHOLOGY OF WISCONSIN OUTWASH SEDIMENTS IN THE WABASH VALLEY

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Variation in the pebble lithology of Wisconsin outwash sediments in the Wabash Valley has been largely controlled by the influx of rock fragments supplied by the local Paleozoic bedrock. The processes of abrasion and selective transportation have amplified the effects of this local bedrock contamination in the coarse size fraction of the outwash sediments. Dolostone, the dominant rock type, and limestone were derived from the Silurian and Devonian formations that crop out in northern Indiana. Limestone was also furnished by the Mississippian formations that are exposed in central and south-central Indiana. Clastics were supplied by the Pennsylvanian formations that crop out in the middle and lower Wabash Valley. Chert was contributed by one or more formations in each of the Paleozoic systems exposed in the Wabash Valley. The igneous and metamorphic rocks whose ultimate source was primarily the Canadian Shield were supplied by the gravel fraction of Wisconsin till deposits.

Downstream variation in the relative abundance of rock types within the 16 to 32-mm size interval for outwash sediments collected from two terraces is similar and indicates that the contributions from the local bedrock remained essentially unchanged during the two periods of sedimentation. The pebble (16 to 32-mm) lithology for the sediments of the two terraces is homogeneous when the frequency by number of the different rock types is compared but inhomogeneous when their frequency by weight is compared. This difference is attributed to the variation of pebble size within the size interval.

ENGINEERING GEOLOGY PROBLEMS OF THE ALLEGHENY PLATEAU

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Engineering-geology problems of the Allegheny Plateau area, the Pittsburgh industrial complex in particular, are influenced chiefly by its physiography, stratigraphy, structural geology, and mineral resources. The excavational, transportational, and depositional activities of that relatively recent geologic agent, man, however, precipitate landslides, mine subsidence, subsurface combustion,

foundation settlement, and allied inconveniences. Briefly discussed are those particular geologic conditions of the area which, reacting with the unusual industrial and cultural developments, permit the engineering geologist to render a very real service to this community.

CHEMICAL COMPOSITION OF SANDSTONES

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One hundred and sixty-eight chemical analyses of sandstones have been collected from the literature and divided according to a primarily tectonic classification into four clans: quartzite ($Al_2O_3 < 5$ per cent), taphrogeosynclinal (arkose), eugeosynclinal (high-rank graywacke), and exogeosynclinal (low-rank graywacke). Histograms for the seven major oxides and variation diagrams for K_2O/Na_2O and alkalis/Al_2O_3 indicate that the tectonic associations group together clans of chemical analyses that differ significantly. The high-rank graywackes especially differ from other sandstones in their low K_2O/Na_2O ratio, which is to be correlated with the presence in them of basic volcanic detritus. Geometric means for the seven major oxides, for the four clans, are as follows:

	Arkose	*High-rank graywacke*	*Low-rank graywacke*	*Quartzite*
SiO_2	82.75	71.40	78.71	93.34
Al_2O_3	10.57	13.84	11.77	3.32
Fe_2O_3	1.95	4.92	3.56	1.49
MgO	0.24	2.21	1.23	0.34
CaO	0.89	2.73	2.39	0.37
Na_2O	0.72	3.11	0.83	0.31
K_2O	2.88	1.79	1.51	0.82
Total	100.00	100.00	100.00	99.99

COLORADO PLATEAU URANIUM-LEAD AGE PROBLEM

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The uranium-lead isotopic relations in the Colorado Plateau uranium mineralizations suggest a complex geochemical history. Further analyses of uranium and lead by isotope dilution and of the lead isotopic composition of a suite of fresh massive pitchblendes have been made. The measurements on specimens from Lisbon Valley, Utah, Temple Mountain, Utah, Cameron, Arizona, and the Ambrosia Lake district, Grants, New Mexico, displayed a similar range in isotopic ratios with the exception of a pitchblende from the Todilto limestone at Haystack Butte, Grants, New Mexico, which shows a lead 207/lead 206 ratio of $0.0361 \pm .0003$. S^{32}/S^{34} ratios have also been determined in all these areas and indicate bacteriological origin for the H_2S involved in the precipitation process.

An additional source for some of the radiogenic lead other than the present uranium is indicated by the apparent ages obtained from the lead 207/lead 206 ratios of all samples except the one from the Todilto limestone. There remains evidence for relatively recent deposition or redeposition of some of the uranium ore.

UPPER DEVONIAN ROCK-STRATIGRAPHIC NOMENCLATURE IN PENNSYLVANIA

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Current, detailed mapping and compilation of the new geologic map of Pennsylvania have shown that desirable rock-stratigraphic names are lacking in the nomenclature of the Upper Devonian of

Pennsylvania. The section involved represents a major sedimentary cycle composed of three fundamental units: a lower marine, an upper nonmarine, and a middle transition unit characterized by intertonguing marine and nonmarine units.

To establish a basis for the organization of known Upper Devonian rock units in Pennsylvania, the writers propose that a series name suggested by Ashley (1923) be modified in definition and accepted as a group name for the rock-stratigraphic framework, and that existing, new, or redefined formation names be applied to the marine, transition, and nonmarine units that constitute the major framework. Local, mappable units that have been named and defined validly as rock-stratigraphic units can be correlated laterally by the tracing of multiple lithologic units and designated as members within or units equivalent to one of the three proposed formations.

The major objective of this report is not to propose a name for the Upper Devonian series, which is a time-stratigraphic unit, but rather to name the rock-stratigraphic unit which is approximately defined by Late Devonian time in Pennsylvania.

NORSETHITE, $BaMg(CO_3)_2$, A NEW MINERAL FROM THE GREEN RIVER FORMATION, WYOMING

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Norsethite, $BaMg(CO_3)_2$, was found in dolomitic, black oil shale below the main trona bed in the Westvaco trona mine in Wyoming, associated with shortite, labuntsovite, searlesite, loughlinite, pyrite, and quartz. It also occurs there in gray shale with abundant shortite and northupite, some searlesite and loughlinite, in a fine-grained matrix, essentially quartz and pyrite.

Norsethite occurs as clear to milky white circular plates or flattened rhombohedral crystals, 0.2-2 mm across. It is insoluble in water but readily decomposed by cold dilute hydrochloric acid. Norsethite has: hardness 3.5; density 3.837 (measured), 3.84 (calculated); luster vitreous to pearly; fracture hackly; good rhombohedral cleavage. It is infusible before the blowpipe.

Optically, norsethite is uniaxial negative; $\omega = 1.694$, $\epsilon = 1.519$. The possible space groups for norsethite are $R\bar{3}m$, $R3m$, or $R32$; the probable space group is $R32$ (D_3^7), a subgroup of $R\bar{3}c$, the space group of calcite. Norsethite, like members of the dolomite group, has a structure similar to that of calcite. Cell constants are: $a = 5.02$ Å, $c = 16.75$; $a_{rh} = 6.29$, $\alpha = 47°02'$. Cell contents: $BaMg(CO_3)_2$ in the rhombohedral unit. Forms observed: $c\{0001\}$, $a\{11\bar{2}0\}$, $m\{10\bar{1}0\}$, $r\{10\bar{1}1\}$. The strongest X-ray lines are: 3.015 Å (100), 3.860 (35), 2.656 (35), 2.512 (35), 2.104 (35), 1.931 (35), 1.864 (35).

Chemical analysis made on a 0.1-gm sample gave: BaO 52.9, CaO 0.5, MnO 0.1, MgO 13.9, CO_2 31.2, total iron as Fe_2O_3 0.4, SiO_2 0.3, insoluble 0.5, total 99.8 per cent.

Norsethite is named in honor of Mr. Keith Norseth, engineering geologist of the trona mine at Westvaco, Sweetwater County, Wyoming.

X-RAY SPECTROCHEMICAL ANALYSIS: AN APPLICATION TO CERTAIN LIGHT ELEMENTS IN CLAY MINERALS AND VOLCANIC GLASS

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Recent developments in instrumentation have extended the range of X-ray spectrochemical analysis (X-ray fluorescence) to elements in the range of atomic numbers 12–22. This includes the significant rock-forming elements aluminum, silicon, potassium, and calcium, in addition to phosphorus, sulfur, and titanium. Improved procedure now provides a rapid, nondestructive, quantitative, semiquantitative, and qualitative analytical method useful in the examination of aluminosilicate minerals and mineraloids. It is also capable of wider application.

The analytical method has been applied to volcanic and related materials from the Marysvale, Utah, uranium area. The X-ray instrument has been calibrated through the use of artificial mixtures

of chemical compounds containing the constituent elements. Previously analyzed reference clay minerals of the American Petroleum Institute Project 49 have served to establish the calibration. X-ray analytical data have been obtained for a selection of specimens from the Mt. Belknap series which forms part of the Upper Tertiary volcanic cover in the Marysvale region. The materials examined include rhyolitic obsidian, volcanic ash, granular igneous rocks and argillic alteration specimens. X-ray spectrochemical analyses of the Mt. Belknap series show a limited compositional range. This indicates that the tuffs, glasses, and rhyolites of this series are derived from a uniform magma.

ALTERATION OF GYPSUM TO FORM THE CAPITAN LIMESTONE OF NEW MEXICO AND TEXAS

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Tracing of key beds indicates that gypsum rock of the Castile formation of Permian age in the Delaware basin may be correlative with the upper part of the Capitan limestone at the margin of the basin and not younger than the Capitan as supposed by previous workers. Evaporite deposits equivalent to the Capitan limestone would therefore lie on both sides of the Capitan, making it seem unlikely that this massive sparsely fossiliferous limestone is a former barrier reef.

Limestone of the Capitan is lithologically similar to limestone of hills in the basin known as "castiles" which were formed by alteration of gypsum along faults. In addition, the Capitan includes angular blocks of dolomite rock and quartz sandstone that seem to have been lithified before they were brecciated. These observations suggest that thin beds of dolomite and sandstone originally interfingered with gypsum which was later altered to form the Capitan limestone. The writer suggests that solutions of meteoric origin moved in Triassic time from outcrop areas of sandstone of the underlying Delaware Mountain group across the basin to the termination of the sandstone facies directly below the Capitan and then upward through the Capitan in response to artesian pressure. Flow of water similar to that postulated to have caused the replacement may still continue, for salt on the east side of the basin has been leached along a narrow belt directly above the Capitan limestone and has formed a linear depression that contains thick surficial deposits of late Cenozoic age.

POTASSIUM-ARGON AGES IN NORTHERN MANITOBA, CANADA

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Potassium-argon measurements made on biotite separated from Precambrian crystalline rocks in northern Manitoba gave the following results:

Location	Latitude	Longitude	K-A age, m.y.
Oxford Lake-Knee Lake	54° 48′N.	95° 35′W.	2170
Oxford Lake-Knee Lake	54° 45′N.	94° 55′W.	1600
Partridge Crop Lake	55° 39′N.	97° 20′W.	1790
Lynn Lake	56° 48′N.	101° 01′W.	1660
Lynn Lake	56° 46′N.	101° 00′W.	1710
Lynn Lake	56° 46′N.	101° 02′W.	1600
Northern Indian Lake	57° 15′N.	97° 31′W.	1690
Northern Indian Lake	57° 21′N.	97° 52′W.	1690
Northern Indian Lake	57° 22′N.	97° 25′W.	1750
Miller Lake	54° 40′N.	99° 55′W.	1710

(Decay constants used are $\lambda_e = .585 \times 10^{-10}$ yr.$^{-1}$, $\lambda = 5.30 \times 10^{-10}$ yr.$^{-1}$.)

The results from Lynn Lake, Northern Indian Lake, Miller Lake, and Partridge Crop Lake suggest that the Churchill geologic province is homogeneous in northern Manitoba. The ages from the Oxford Lake-Knee Lake area are typical of "mixed-age" zones resulting from the recrystallization of older rocks in the vicinity of a younger orogenic belt and are interpreted as indicating that the normal host rock in the Oxford Lake-Knee Lake area should be included in the Superior geologic province, although it does not show the usual 2400-2600 m.y. age.

BEDROCK TOPOGRAPHY OF WAYNE COUNTY, MICHIGAN

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Data on depth to bedrock are being collected for eight counties in southeastern Michigan to determine the preglacial drainage pattern as well as the changes imposed upon this pattern by Pleistocene glaciation. A preliminary map of the bedrock topography for Wayne County reveals clearly the following features: (1) a preglacial valley which approximates the present course of the Detroit River but whose gradient is to the northeast, (2) a well-defined preglacial tributary to this valley which is now traceable from its junction at Belle Isle (Detroit) northwestward for 25 miles to the City of Pontiac (Oakland County), (3) several other small but clearly established preglacial tributaries which pass through or near the cities or villages of Northville, Plymouth, Belleville, and New Boston, and (4) a northeast-southwest cross channel of glacial age, which cuts across the preglacial tributaries just mentioned and is situated roughly along the boundary between the Erie-Huron lowland and the Thumb upland. Scattered data in adjacent counties reveal bedrock elevations that are significantly lower than the lowest elevations encountered in Wayne County. Thus, the distribution of bedrock uplands and lowlands as presently known in Michigan and the general lobation of the Wisconsin glacier indicate that the preglacial drainage of the region was undoubtedly blocked during an ice advance. The general effect of this produced temporary proglacial lakes, cross channels, and reversals in the direction of the existing drainage.

NEW DATA ON THE HYDRATED SCANDIUM PHOSPHATE MINERALS: STERRETTITE, "EGGONITE", AND KOLBECKITE

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As part of a systematic investigation of phosphate minerals, crystals of sterrettite from Fairfield, Utah, sterrettite (eggonite) from Altenberg, Moresnet, Belgium (?), and kolbeckite from the Sadisdorf copper mine, near Schmiedeberg, Saxony, were studied by X-ray-diffraction techniques. Sterrettite previously had been reported to be a hydrated aluminum phosphate and kolbeckite a hydrated silicate-phosphate of aluminum, beryllium, and calcium.

X-ray-powder diffraction and precession photographs established that these minerals have the metavariscite type of structure; their general chemical formula is, therefore, $A(XO_4)\cdot 2H_2O$. Powder patterns of sterrettite and kolbeckite showed that their cell sizes are identical with that of synthetic $Sc(PO_4)\cdot 2H_2O$ (Maxwell Carron), indicating that the major cation might be scandium rather than aluminum; the cell size of metavariscite, $Al(PO_4)\cdot 2H_2O$, from Lucin, Utah, is considerably smaller. X-ray fluorescence analysis on a very limited number of available crystals proved that scandium is present as a major cation in both minerals. Thus the probable formulas are: $Sc(PO_4)\cdot 2H_2O$ for sterrettite; $(Sc,Be,Ca)(SiO_4,PO_4)\cdot 2H_2O$ for kolbeckite.

Crystallographic data obtained in the present study are:

	Sterrettite (Fairfield) Monoclinic; $P2_1/n$	*Sterrettite (Altenberg) Monoclinic; $P2_1/n$*	*Kolbeckite (Schmiedeberg) Monoclinic; $P2_1/n$*	*Metavariscite (Lucin) Monoclinic; $P2_1/n$*
a	5.44_5 Å	5.44_7 Å	5.44 Å	5.18_0 Å
b	10.25	10.25	10.25	9.51
c	8.93	8.93_5	8.93	8.47
β	90°45′	90°45′	90°40′	90°25′
Z	4	4	4	4
Density (calculated)	2.35	2.35	2.28	2.52
Density (measured)	2.36	2.35	2.39	2.52

Sterrettite and kolbeckite are the first known scandium-bearing phosphates. Sterrettite is the first scandium-rich mineral found in the United States. This study confirms Bannister's conclusion that eggonite is sterrettite.

GLACIAL GEOLOGY OF THE LAGUNA SAN RAFAEL AREA, SOUTHERN CHILE

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San Rafael Glacier (Lat. 46° S.), on the west slope of the Chilean Andes, was selected by the American Geographical Society* for study of the Late Pleistocene environmental succession because its location in the Southern Hemisphere is analogous to that of the well-studied Juneau Ice Field in the Northern Hemisphere.

Exposures in bluffs bordering Laguna San Rafael and the Rio Tempanos and in abandoned canal excavations at Ofqui afford evidence of three major glaciations, of which two are represented by groups of moraines in the San Rafael area. Similar chronologies are indicated for Guala and other nearby glaciers.

Evidences of early glaciation indicate a transection glacier which spread westward toward the outer islands, producing the intensely fiorded coast line.

An expanded foot phase of glaciation is marked by three closely associated moraines roughly parallel to shores of Laguna San Rafael. Acid soil waters of the rainforest (pH about 4.5) cause cementation, giving till bluffs a misleading appearance of age. The associated moraines by their location and freshness appear to mark fluctuations comparable to late phases of the waning Wisconsin glaciers in Alaska.

A succession of moraine ridges 5–10 m high near the glacier margin marks glacial advance and retreat of several km within recent centuries. In early 1959 the glacier was again spreading into areas uncovered for 3 decades.

LEAD ISOTOPIC STUDY OF ORE AND IGNEOUS MINERALS AT BUTTE, MONTANA

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Isotopic composition of lead in the ores and igneous rocks at Butte, Montana, indicates that the relation between ores and associated igneous rocks is far more complex than is generally assumed for

* Supported by Office of Naval Research

a simple hydrothermal ore deposit. The lead in the quartz monzonite is distinctly more radiogenic than the lead in the ore. The rock and ore leads are either derived from two different sources, or they represent different mixtures of at least two types of leads. Hence, in this case, the parental relationship of igneous rock to the ore is doubtful.

The isotopic composition of lead in feldspar either from the igneous rock or pegmatites is dependent upon the degree of alteration of feldspar. The less altered feldspar has lead with a composition closer to that of the rock, whereas the more altered feldspar lead resembles that of ore. This dependency of the composition of lead on the degree of alteration is interpreted as due to the mixing of original feldspar lead with ore lead introduced into the feldspar at the time of alteration.

ANALYSES OF THE ORGANIC COMPONENTS OF THE ATHABASCA OIL SAND IN ALBERTA, CANADA

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The organic contents of two sets of samples were analyzed. Two weathered samples from the Abasand Quarry near McMurray were used for an evaluation of analytical procedures, and 53 smaller samples taken from cores of a bore hole drilled near Bitumount, were used for a study of the variations in composition along a vertical traverse. The rocks were extracted with methylene chloride at room temperature.

Alumina and silica-gel columns were charged with the bulk extracts of the Abasand Quarry samples and were eluted with the same series of solvents: (1) n-heptane, (2) carbon disulfide, (3) carbon tetrachloride, (4) benzene, (5) methylene chloride, (6) chloroform, (7) diethyl ether, (8) pyridine, (9) ethyl acetate, (10) methyl alcohol, and (11) ethyl alcohol. Other factors affecting separation efficiency, such as the adsorbent/sample ratio, were included in the study. In general, elution on alumina produced better defined bands than on silica gel.

The Bitumount samples were collected at every 5 feet of core throughout the total thickness of the McMurray formation, which is approximately 250 feet in this area. In five zones the amount of the organic matter that was soluble in CH_2Cl_2 was higher than 10 per cent of the weight of the rock but less than 17 per cent. Between these five zones the sediments contained 0–10 per cent soluble organic matter. Differences in composition were observed throughout the cores, and the aromatic character and the presence of oxygen containing compounds in the extracts were shown by infrared spectra.

RELATIONSHIP OF THE BAIE VERTE GROUP TO GNEISSIC GROUPS OF BURLINGTON PENINSULA, NEWFOUNDLAND*

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Northwestern Burlington Peninsula is largely underlain by ophiolitic rocks of the Baie Verte group and quartz-feldspar gneisses and schists of the Fleur de Lys and Mings Bight groups. The Baie Verte group is classified as Ordovician. The gneissic groups have hitherto been classified as Precambrian on the basis of lithology, metamorphism, and relationship to Baie Verte group. The apparent time hiatus is used to support paleontological evidence of the "New Brunswick Geanticline" which divided Newfoundland into two basins of deposition in Cambrian time.

Recent work casts doubt on a large time or structural break between gneisses and Baie Verte group. North of Marble Cove, northeast-striking green schists mapped as Baie Verte are conformably intercalated with Fleur de Lys gneisses. These green schists are on strike with and lithologically

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similar to the Birchy schist formation, a conformable member of Fleur de Lys group. A previously described faulted contact on the north shore of Marble Cove is reinterpreted as a metamorphosed contact between a Baie Verte basic sill and Fleur de Lys gneiss. These rocks belong within the green schist facies; westward the gneisses grade into almandine amphibolite facies.

At Pacquet Harbour, the contact of Mings Bight gneisses and Baie Verte group, previously interpreted as an unconformity, is reinterpreted as occurring at Marble Cove. Here both groups belong within the almandine amphibolite facies.

As the gneissic groups are conformable with and have a metamorphic history similar to the overlying Baie Verte group, the writer concludes that they are of Paleozoic age.

NEW BENTONITE ZONE FROM THE PENNSYLVANIAN OF SOUTHWESTERN VIRGINIA

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A bentonite occurs below the Pardee coal in the upper Wise formation (Pennsylvanian) near the head of Critical Fork, 8 miles northwest of Wise, Wise County, Virginia. The bentonite is a stratum interbedded in the local succession of sandstones, shales, and coals, as follows:

	Feet	*Inches*
Medium-gray, marcasitic, silty-clay shale with plant fragments	3	6
Bituminous coal (Pardee or next lower local coal)	4	0
Black, hard, very carbonaceous shale		2
Tan, silty clay (bentonite)	1	6
Black, hard, very carbonaceous shale		4

The gray, silty-clay shale and the black, carbonaceous shale contain the clay minerals illite, kaolinite, and chlorite. The bentonite mineralogy contrasts strongly with that of the associated shales. It contains montmorillonite and a small proportion of kaolinite. The air-dried montmorillonite gives a 13.8 Å X-ray-diffraction peak, which shifts after glycolation to 17.5 Å.

Petrographically the bentonite consists of feldspar and quartz phenocrysts in a groundmass of montmorillonitic clay. No relict shard structures can be detected in the groundmass. The feldspar is untwinned potassium feldspar with small 2V, probably sanidine. A few of the quartz phenocrysts are euhedral and exhibit the pyramidal habit characteristic of high-temperature quartz. Euhedral apatite and zircon crystals also are present. The petrography is consistent with a volcanic origin.

ROLE OF CLAY IN STYLOLITE FORMATION

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Stylolites occur in many kinds of limestones, but they are found most commonly in strata of rather high "purity." In "impure" rocks where clay is thoroughly disseminated, the sutured contacts between individual calcite grains are abundant, and distinct stylolites are not commonly observable.

Clay partings are invariably present in stylolites, and they generally consist of micalike clay. This clay may not take part in reaction directly, but it may have an effect on the velocity of solution and act as a catalyst. The action of clay depends on its power of concentrating and orienting water molecules at its surface. Such oriented water, adsorbed on polar mineral surface, has different solvent and ion-exchange properties from bulk water. Dissolved Ca^{++} is in equilibrium with the Ca^{++} in the limestone. When these ions are adsorbed on clay surfaces, more Ca^{++} goes into solution in order to maintain the equilibrium. Therefore stylolites may be related to differences in the solvent properties of pore water and water adsorbed on clay layers.

Solution and diffusion of calcium carbonate along the adsorbed water layers may exceed that in capillary (pore) systems because of the large surface area and the well-ordered system within it. Thus, at the sutured grain contacts where clay does not occur solution may proceed very slowly, and stylolites do not form.

Vertical stylolites are rare and generally occur only in zones of structural activity where faults and pressure joints are common.

CLASSIFICATION OF RAPID MASS MOVEMENTS

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The description of slush avalanches as an effective mechanism of downslope transport of rock debris in arctic regions points up the necessity for an all-inclusive classification of rapid mass movements. Sharpe's dichotomy of classification into rapid and slow flowage is a useful and effective tool in discussing downslope movements, but a greater refinement of concepts is desirable, especially for rapid mass movements.

The classification proposed here is based on the bulk composition of the flowing mass and utilizes a triangular diagram that has end members water, snow, and rock fragments. An even more effective approach is to use a tetrahedron that has water, snow, coarse rock fragments, and fine rock fragments as the four end members. This latter approach categorizes such well-known phenomena as landslides and rock falls, establishes the position of slush avalanches as an explicit geologic agent, and leads to an examination of the relationship between normal stream flow and mudflows. The serious lack of quantitative data on the character of mass movements at the time they occur limits sharp differentiation of the boundaries of the several classes of movement and suggests that such data should be sought for normal stream flow, for mudflows, and for slushflows. A normal extension of this reasoning leads to the use of tetrahedra for studies of any combination of geomorphic agents.

TELLURIC CURRENTS AS A SOURCE OF ENERGY IN GEOCHEMICAL PROCESSES

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Telluric currents, simultaneous in Universal Time, have been measured over thousands of miles. They seem closely connected with diurnal changes in the nondipole part of the earth's magnetic field but are locally affected and deflected by variations of resistive elements in the geologic pattern. The currents do not cancel out when plotted on a vector diagram but rather are irreversible with an unbalanced cumulative effect. Hence, this implies a net directional ionic transfer. The magnitude of the currents is sufficient to produce significant electrochemical results in geologic time. Telluric currents must, therefore, play a role in diagenesis, metamorphism, granitization, the separation of elements in silicate melts, natural phase equilibria, and the transportation and deposition of elements found in ore deposits. Although peculiarities of telluric currents and their possible geochemical effects need further study, it appears certain that they may be considered another major source of energy in the geochemical cycle.

ION-EXCHANGE REACTION BETWEEN SYNTHETIC ALKALI FELDSPARS AND ALKALI CHLORIDE SOLUTIONS

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Synthetic alkali feldspar and 2-molar alkali chloride solution react by ion exchange at temperatures as low as 300° C. Experimental results are presented on coexisting alkali chloride solution and

alkali-feldspar assemblages at two different temperatures and 2000 bars pressure. At 700° C. one feldspar plus alkali chloride solution is the only phase assemblage present for all bulk compositions. Equilibrium partitioning of Na and K between feldspar and vapor phases is closely approached within 24 hours. At 600° C., below the crest of the alkali feldspar solvus, a three-phase invariant assemblage consisting of two feldspars plus alkali chloride solution is bounded by one feldspar plus alkali chloride solution assemblages. Subsolidus reactions proceed more rapidly in the presence of alkali chloride solution than in the presence of pure water. An alkali feldspar solvus has been determined by this method.

The total concentration of alkalies in the solution does not appear to be important, for similar results have been obtained for solutions 0.2 and 2.0 molar in total alkalies.

At all temperatures below the crest of the alkali feldspar solvus the solution coexisting with two feldspar phases is rich in Na relative to K, and it becomes progressively richer in Na with falling temperature.

UNIT-CELL DIMENSIONS OF RECENT AND FOSSIL TOOTH APATITES

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Calibrated-camera powder X-ray photographs have been used to calculate unit-cell dimensions of apatite in 40 samples of recent and fossil vertebrate tooth materials. Most samples consisted of untreated tooth enamel. In general, fossil tooth apatites differ from those of recent animals in having shorter a axes and longer c axes and approach the dimensions of inorganic sedimentary carbonate-apatites. Among recent animals, it appears that tooth apatites of marine mammals have shorter a axes than those of strictly terrestrial mammals, and that the apatites of shark teeth have shorter a axes than those of other fish. The average c axis length of recent fish and shark apatites is shorter than the average of terrestrial animals. Among the fossils, the tooth apatites of land dwellers tend to approach dahllite (carbonate-hydroxylapatite) in cell dimensions, and the dimensions of shark and fish apatite approach those of collophanite (carbonate-fluorapatite). Some representative tooth apatite dimensions, in Angstrom units, are as follows (c axis and a axis respectively): human, 6.885, 9.45; Miocene rodent, 6.895, 9.40; Recent lungfish, 6.882, 9.42; Permian lungfish, 6.890, 9.37; Recent shark, 6.880, 9.39; Permian shark, 6.888, 9.37. Comparison with inorganic and invertebrate apatites leads to the conclusion that fluoridization alone is not the cause of the change with time of vertebrate tooth apatite unit-cell dimensions.

COPRECIPITATION OF STRONTIUM WITH CALCIUM CARBONATE FROM AQUEOUS SOLUTIONS

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Coprecipitation of Sr^{++} ions with $CaCO_3$ has been studied by means of two techniques at 30°C. and 95°C. Rapid dissociation of calcium trichloroacetate at temperatures above 90°C. was the basis of one technique. A solution of calcium chloride, calcium trichloroacetate, and strontium chloride was heated to 95°C. Part of the strontium was Sr^{85}, a radioisotope of strontium. The $CaCO_3$ precipitated by the dissociation of the trichloroacetate was permitted to digest for 1–3 days and was subsequently separated by filtration. The filtrate was analyzed for strontium radiometrically and for calcium plus strontium by means of an EDTA titration. The precipitate was X rayed and studied optically and was then dissolved and analyzed like the filtrate.

In the second method of precipitating $CaCO_3$ carbon dioxide was passed into an ammoniacal solution of calcium chloride and strontium chloride. Separation and analysis of the solid and liquid phases were carried out as in the trichloroacetate technique.

The distribution coefficient, K, defined by the equation

$$\left(\frac{Sr^{++}}{Ca^{++}}\right)_{crystal} = K\left(\frac{Sr^{++}}{Ca^{++}}\right)_{solution},$$

was computed from the experimental data. For aragonite at 95°C., $K_A^{95°C.} = 0.66 \pm 0.02$. The value of K is essentially constant over a wide range of solution composition. For calcite $K_C^{95°C.} = 0.070 \pm 0.004$, and $K_C^{30°C.} = 0.11 \pm 0.02$. These results indicate that Sr^{++} ions are much more readily precipitated with aragonite than with calcite and permit the estimation of the ratio (Sr^{++}/Ca^{++}) in solutions from which these minerals have been deposited. The present data are of particular interest in connection with the formation of calcium carbonate in sediments and in epithermal ore deposits.

OCCURRENCE OF CARBOHYDRATES IN BITUMINOUS SEDIMENTARY ROCKS*

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Preliminary chemical investigations have indicated the presence of carbohydrates in bituminous sedimentary rocks ranging in age from Ordovician to Tertiary.

Initial studies, conducted on a core of *Elliptio*-bearing Green River black shale of Eocene age, showed the presence of furfural and 5-hydroxy-methylfurfural in the distillate fraction collected after reacting the powdered rock sample with boiling 12 per cent HCl. The compounds were determined by distinct color reactions and absorption spectra. Furfural and 5-hydroxy-methylfurfural are produced by the reaction of strong acids on pentoses and hexoses, respectively. This new information prompted further characterization of the parent carbohydrate constituents.

Thoroughly cleaned samples from outcrops and from well cores, consisting mainly of black shales and limestones, were treated with dilute sulfuric acid on a boiling water bath. Removal of inorganic material by centrifugation, alcohol precipitation, and ion-exchange resins, provided a residue that was shown by paper chromatography to contain sugars whose R_f or R_g values corresponded to glucose, arabinose, and xylose. There were also indications of galactose and rhamnose. Glycerol was also detected chromatographically.

These compounds are believed to be original constituents of the rocks, although in the outcrop samples, despite careful collection and subsequent cleaning treatment, the possibility of contamination by ground waters or other agencies cannot be dismissed. Free sugars in small quantities were detected in one of the rock samples, but most of the monosaccharides here obtained are believed to occur in the rocks as polysaccharides or oligosaccharides.

DESCRIPTION AND ORIGIN OF STONE LINES (CARPEDOLITHS) NEAR THE KANSAN DRIFT BORDER IN NORTHEAST KANSAS AND NORTHWEST MISSOURI

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Stone lines are exposed in a few places immediately north and south of the Kansan drift border in Missouri and Kansas. The fragments that compose stone lines are chiefly chert, although limestone and glacial erratics occur in some layers. The fragments are normally angular, ranging from 0.5 to 4 inches in diameter. Cherts in the stone lines are derived principally from the Westerville (Kansas City group) and Plattsburg (Lansing group) limestones of Pennsylvanian age exposed in this locality. An anomalous condition is the lack of dark chert from the cherty Winterset (Pennsylvanian) limestone of this region as a significant component of stone lines.

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The stone lines in Missouri and Kansas differ from those in North Carolina, South Carolina, and Georgia in that they are: (1) generally more homogeneous in composition, (2) of lesser individual areal extent, (3) almost exclusively linear and multilayered in aspect, and (4) everywhere underlain by alluvial silts and clays.

The composition and physiographic setting of the stone layers in Missouri and Kansas indicate a mode of development identical with those in the southeastern United States. They represent former transported surface deposits that have been buried by slope wash and colluviation. There is no evidence to support the recent statement of Crain (1958) that stone lines represent highly weathered remnants of lenses and layers of rock *in situ* rather than transported materials.

PLANT MICROFOSSILS AND AGE OF NONMARINE CRETACEOUS SEDIMENTS OF MARYLAND AND DELAWARE

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The molluscan, vertebrate, and plant-foliar fossils of the nonmarine Cretaceous deposits of Maryland and Delaware, collected and studied between 1896 and 1952, have not contributed to unanimity of opinion concerning the boundary between Early and Late Cretaceous or to the correlation with the European sections. Seeking another category of fossil evidence, the authors have demonstrated that spores and pollen can be isolated in good quantity and preservation from these disputed sediments. At the time of this report, 23 selected species (11 new) of fern spores, as well as gymnosperm and angiosperm pollen have been described. These have been isolated from samples taken from 4 outcrops and 2 well corings that span the nominal Patuxent, Arundel, Patapsco, and Raritan "formations". The floral assemblages, compared with those of similar European studies, indicate an age range from Neocomian for the stratigraphically lowest to Cenomanian for the highest sediments. The conventional formation assignments of the Potomac group have shown no logical correlation with the age of the sediments indicated by these present pollen studies; thus the question of the validity of the formational designations or their field mapping is raised again.

MULTIPLE GLACIATION IN THE McMURDO SOUND REGION, ANTARCTICA

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At least four major Quaternary glaciations, each successively less extensive than the preceding one, are recorded in the McMurdo Sound region of Antarctica. Deposits of the earliest recognized glacial advance, the McMurdo glaciation, occur high on ridges and flat areas. The deposits are 2000 feet above the valley floor, are badly weathered, and have little or no morainal form. Ice of this glaciation filled all the valleys and must have filled McMurdo Sound to an elevation of 2000 feet.

Deposits of the next two succeeding glaciations are distributed around the sound as well-preserved but considerably subdued moraines of both outlet and alpine glaciers. During the earlier of these two glaciations, alpine glaciers reached the expanded Koettlitz and Ferrar outlet glaciers. Outlet glaciers filled the southern part of McMurdo Sound to an elevation of about 1200 feet. During the latter of these two advances many alpine glaciers did not reach the outlet glaciers.

The latest major glaciation is represented by well-preserved ice-cored moraines. Number and position of deltas in drained glacier-ice-blocked lakes suggest two or possibly three stillstands or minor advances during this glaciation. Radiocarbon dating of algae in drained ponds indicates a minimum age of 6000 years for this glaciation.

CHEMICAL AND PHYSICAL STUDIES OF TEKTITES

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A study of some of the chemical and physical properties of tektites is currently in progress. The purpose of this study is to test the hypothesis that geographical groups of tektites are homogeneous enough physically and chemically and different enough from any terrestrial rocks to make their meteoritic origin highly probable, and essentially to exclude a terrestrial origin.

Previous mass spectrometric analyses have demonstrated uniform Rb contents but a range from 110 to 290 ppm Sr in a few tektites from the Philippines, Australia, Indo China, and Czechoslovakia. Emission spectrograms indicate nearly identical trace-element compositions for Indo Chinites and Philippinites.

Specific-gravity measurements of 39 tektites from the Philippines and Indo China indicate a range from 2.43 to 2.46 for 35 samples; 4 samples range as low as 2.34. However, bubbles apparently account for these lower densities. Indices of refraction are uniform at 1.51 for 4 samples from 3 provinces in the Philippines. Of 11 Philippinites and Indo Chinites from several localities, the following compositions were found chemically: 1.9 ± 0.1% K; 1.0 ± 0.1% Na; 3.9 ± 0.2% Fe; 0.46 ± 0.02% Ti; and 0.07 ± 0.01% Mn. The range is expressed as standard deviations from the means. No anomalous compositions were found. An Americanite (Philippines) is similar physically and chemically to obsidian and markedly unlike the other tektites.

THREE AGES OF ROCK CRYSTALLIZATION IN COLOMBIA, SOUTH AMERICA

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Biotite samples from basement rock at approximately 3° 0′N., 70° 43′W. in the western part of the Guayana Shield in Colombia yielded A/K ages of 1210 million years. Two hundred kilometers to the west, near San José del Guaviare, at the extreme western edge of the eastern plains (llanos) of Colombia, other basement-rock biotites yielded A/K ages of 450 million years. One hundred and twenty-five km west of San José del Guaviare, folded Cambro-Ordovician strata overlie basement crystalline rocks at the Macarena Mountains.

Granitic basement from the Cicuco oil field, Department of Bolivar, Colombia, is 120 million years by the A/K measurement of biotite. These rocks are overlain at Cicuco by Oligocene limestone and may correlate with intrusive rocks of known Jurassic age 80 km farther southeast.

DISTRIBUTION OF THORIUM AND URANIUM IN THE MANCOS SHALE (CRETACEOUS)

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More than 135 samples of the upper Cretaceous Mancos shale have been analyzed for uranium, thorium, and potassium by chemical and radiometric means. These samples were collected from 16 localities in Colorado, Utah, Arizona, and New Mexico. The average concentrations found in the shale samples are 10.2 ppm thorium, 3.7 ppm uranium, and 1.9 per cent potassium as the metal.

For the most part, the variations in the thorium, uranium, and potassium concentrations in the Mancos shale are gradual and take place over large distances both vertically and horizontally. Thorium, Th/U ratio, and potassium tend to decrease, and uranium tends to increase with distance from the late Cretaceous shore line. The K/Th ratio in the shale, including sandy intertongues, shows remarkably little variation on a regional basis.

Laboratory studies indicate that the uranium in the Mancos shale is present largely in the fine-

grained primary resistate minerals, and that the thorium occurs in the fine-grained secondary resistates or fixed in clays.

DISTRIBUTION OF THORIUM AND URANIUM IN A PENNSYLVANIAN WEATHERING PROFILE

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Thirteen samples representing a pre-Pennsylvanian weathering profile on the Boulder Creek granodiorite near Boulder, Colorado, have been analyzed for thorium and uranium by gamma-ray spectrometric and chemical methods. In an effort to determine the possible sites of thorium and uranium in these samples a study of their leachability in acid solutions was undertaken.

The fresh granodiorite was found to contain 9.3 ppm thorium and 2.5 ppm uranium. The first stages of weathering resulted in an apparent removal of 25 per cent of the thorium and 60 per cent of the uranium present in the original granodiorite. The leaching study of the fresh rock demonstrated that as much as 90 per cent of the thorium and 60 per cent of the uranium could be removed by an acid leach solution. This seems to indicate that most of the thorium and uranium in the fresh rock is situated in acid soluble minerals or in interstitial materials.

After the initial drop of the concentration in the lowest part of the weathered mantle, the total uranium and thorium content of the weathered rock increases by a factor of 4 or more in the uppermost, most weathered rock material. Leaching studies of the weathered rock indicate that the uranium is present largely in the primary resistates, such as zircon, xenotime, and apatite, and the thorium occurs mainly in the secondary resistates, probably hydrolyzates or in clays.

SILICA-CEMENTED SANDSTONE AS A GUIDE TO UNOXIDIZED URANIUM DEPOSITS IN THE SOUTHERN BLACK HILLS, SOUTH DAKOTA

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Spatial relations between silica-cemented sandstone and unoxidized uranium deposits in the southern Black Hills indicate that such silica-cemented sandstone may represent a broad alteration halo both stratigraphically above and laterally adjacent to areas of primary uranium deposits. Highly corroded quartz grains in specimens of carbonate-rich uraninite-coffinite ore suggest that silica was leached during the process of mineralization. The silica not used in the formation of coffinite migrated in ground water until precipitated to form the silica-cemented sandstone.

A cursory review of the chemistry of silica, uranium, and calcium carbonate suggests the following process: Uranium traveled as a carbonate complex in carbonate-rich waters in channel sandstones. Where geologic conditions allowed the release of CO_2 and the addition of reducing solutions, calcite precipitated, followed by uranium minerals. Such conditions seem to be present where pinching out of an impervious mudstone unit has resulted in contact between a channel sandstone and an overlying channel sandstone. Silica was released during the replacement of quartz by calcite and migrated in ground-water solutions that were concentrated perhaps up to the saturation point for quartz. Subsequent precipitation of silica as quartz overgrowths and chalcedonic cement may have been caused by a reduction in the temperature of the ground water, or alternatively by equilibration of dissolved silica with quartz in stagnated water trapped in structural highs.

Silica-cemented sandstone may, therefore, be a valuable guide to ore during exploration for "blind" uranium deposits in the southern Black Hills.

STRATIGRAPHY AND STRUCTURE IN THE CENTRAL TACONIC REGION, NEW YORK*

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The stratigraphic section in the fully mapped 7½-minute Eagle Bridge quadrangle and parts of adjacent quadrangles includes: Lower Cambrian Bomoseen siltstone, Mettawee purple and gray slate with trilobite-bearing limestone lenses, dark-gray calcareous slate with lenticular beds of massive quartzite and Eddy Hill grit, fossiliferous limestone lenses in gray slate, black chert, and thin-bedded quartzite; Lower Ordovician fossiliferous limestone and dolomite; Middle (?) Ordovician Deepkill (?) pyritiferous black slate, Eagle Bridge quartzite, laminated gray argillite, and cherty slate; Middle Ordovician Normanskill thin-bedded quartzite, red slate, bedded chert, graptoliferous black slate, and graywacke.

The distinctive Normanskill graywacke ranges in thickness from 15 to about 1000 feet within the Eagle Bridge quadrangle; it is thickest in the southeast and southwest parts. Within 2 miles east of the quadrangle the graywacke grades into the Middle Ordovician Walloomsac slate.

Deepkill (?) and Normanskill (including a thin graywacke section) formations have been thrust westward over a thick Normanskill graywacke section in the southeast part of the quadrangle. Although Prindle and Knopf (1932) mapped this as one segment of their "Taconic thrust", the evidence indicates no great distance of tectonic transport.

Northeast-trending high-angle reverse faults are the most obvious major structures. The relative movement on about half of these faults was west over east.

LOCAL PLEISTOCENE DEFORMATION OF BASIN SEDIMENTS IN THE ARGENTINE ANDES

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Deformed continental sedimentary rocks are exposed south of Santa Rosa de Pastos Grandes, northwestern Argentina, in one of many intermontane basins of the Puna, a high desert region of subparallel north-trending block-fault ranges. These rocks, formerly thought to be of Tertiary age, recently have been dated by fossil diatoms as Pleistocene or Recent. They comprise several thousand feet of clastics and evaporites interpreted as structural-basin sediments deposited under geologic and climatic conditions much like those of today. They are overlain unconformably by deposits of three distinct depositional periods; the stratigraphic sequence is Pleistocene or Recent basin sediments, unconformity, gravels, unconformity, lake beds, disconformity, Recent fan gravels and playa deposits.

The basin sediments are folded along north-trending axes and are cut by northeast- to southeast-trending normal faults and by a north-trending reverse fault; the next younger gravels are gently folded; the two youngest units are undisturbed. The unconformities, the faults and folds in the older beds, and post lake-bed faulting of an erosion surface on an adjacent block all indicate crustal instability in Late Pleistocene or Recent time.

The regional pattern of normal block faulting suggests regional tension, which is apparently incompatible with the compression indicated by the pattern of structures within the basin. The incompatibility is resolved if the compression within the basin is considered as a local effect of the regional faulting. Differential vertical movements of crustal blocks, rather than lateral compression or tension, are inferred to be the mechanism involved.

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INFLUENCE OF PALEOSTRUCTURAL ELEMENTS ON THE LOWER PALEOZOIC STRATIGRAPHY OF EASTERN PENNSYLVANIA

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Changes in facies, thickness, and general distribution of lower Paleozoic formations in the folded Appalachian belts of eastern Pennsylvania are believed to be due mainly to the influence of three linear, subparallel paleostructural elements.

The Adirondack Arch, current barrier in late Cambrian and early Ordovician times, separated predominant dolomite and limestone facies on the west and east respectively. Ordovician Chazy limestones overlap the arch from the east, and the upper beds only pass to the west. Black River limestones disappear east of the arch. Lower Trenton limestones converge from either side of the arch and change facies, whereas middle Trenton and later rocks are not affected.

The Harrisburg Arch indicated intermittent activity from Ordovician Chazy to Devonian Oriskany time. Chazy limestones overlap from the west, the uppermost beds passing the arch and changing facies. Lower Trenton limestones change facies abruptly at the arch. Cincinnatian shales (Maysville phase) and the Devonian Oriskany sandstone offlap underlying rocks and disappear abruptly at the arch, either by erosion or nondeposition.

The Reading Arch, coinciding with the present Blue Ridge trend, showed upward activity at least two times between late Cambrian and late Ordovician. The first furnished interformational conglomerate to middle Trenton limestones from western New Jersey to east of Harrisburg, Pennsylvania. Erosion following a later uplift created an unconformity equal to the entire lower Ordovician and pre-Sherman Fall middle Ordovician.

BED LOAD AND STREAM ENTRENCHMENT

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Bed load is defined as sedimentary material moved on the stream bed. The portion of bed load in contact with moving water is transported fastest. The portion in contact with the stream bed is transported slowest. The average rate of bed-load transportation is in part a function of the thickness of the material in transit but is vastly slower than stream velocity.

Caliber of bed-load material depends partially on stream velocity. Silt may represent bed load for sluggish streams, sand for average streams, and gravel for high-velocity streams.

Sand grains and coarser particles tend to lodge on the stream bed with respect to the prevailing current direction and remain immobile despite velocities and competence more than adequate to move free grains. Transportation of such particles is resumed when current direction changes sufficiently to provide a new angle of attack.

Under conditions where bed load is thick enough to carpet a stream bed, corrasion is mostly confined to wear within the bed-load material. The stream bed is thus protected from erosion, and entrenchment cannot take place. Stream entrenchment is not directly a function of velocity, grade, or environmental conditions but simply a matter of quantity and nature of clastic sediment in transport.

Entrenchment or arroyo cutting occurs, regardless of other factors, where current velocity and fluctuations are sufficient to maintain all clastics in suspension, or where bed-load material is unavailable. Otherwise, the per cent of sand in the parent sediment may control the depth of entrenchment.

EROSION CYCLE FOR THE SANDY FLATLANDS OF THE ATLANTIC COASTAL PLAIN

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The sandy flatlands are capable of absorbing much rainfall and carrying it by subterranean drainage to a few perennial streams, and to the sea. Sinkholes of low relief are the dominant landforms, whether they are the irregular basins of the Coastal Plain of New Jersey or the classical Carolina bays. A compound origin for the basins and "bays" is as follows:

Basin phase: (1) Initial slight depression concentrates runoff. (2) Percolating waters clean the sand beneath the depression by taking suspended clays and colloids (and some solute) to the basin floor, or to the nearest streams, deepening the center of the basin in preference to the rims, as in a sinkhole. (3) A water-table pond is developed.

Bay phase: (4) Wind generates waves which round the shore line of the pond and elongate the pond in direction of prevailing wind, usually as an oriented ellipse. (5) Continued sinking permits capture of one basin by another.

A geomorphic cycle for erosion in sandy flatlands is described in which the basin phase is youth and early maturity, the bay phase is later maturity, and the drainage of the bays by incursion of streams is old age.

ORIGIN OF THE "BAYS" AND BASINS OF THE ATLANTIC COASTAL PLAIN

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A basin is defined as a depressional landform having centripetal drainage. It can be outlined on maps by a closed contour line, marked by hachures, and is recognizable on a photograph, or on the ground, particularly after rain has created ponded water. The term bay is applied to those basins that have symmetrical form and a tendency toward selective orientation. The regular form may be circular, elliptical, or oval; the orientation of the long axis is commonly northwest.

Twenty hypotheses of origin for bays and basins of the Atlantic Coastal Plain are reviewed briefly. The "meteorite" hypotheses for the bays and the various periglacial hypotheses for the basins are found to have serious defects. Johnson's complex "artesian-solution lacustrine-eolian" hypothesis is found untenable.

The writer proposes that a basin is a forerunner of a bay. He agrees that, as suggested by Johnson and others, those basins situated most favorably on the hydraulic grade line retain ponded water in a lacustrine phase, to become rounded and oriented by the wind into the form of a bay. The ground water is not artesian, however, but part of the shallow unconfined water body.

Initial sedimentational depressions are deepened, in part by solution of alumina, iron, and lime but chiefly by removal of suspensoids, the colloids and fine clays. The bay and basin origin is thus a compound origin, a "water table-sinkhole-lacustrine-eolian" progression.

ORIENTATION OF CALCITE C AXES IN ECHINOIDS

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Each element of an echinoderm skeleton is a single crystallographic unit of calcite. A petrographic microscope equipped with a universal stage is used to determine orientations of c axes in thin sections of coronal plates of Recent and fossil echinoids. Data from 43 echinoid species representing 13 families indicate that two preferred orientations dominate the groups studied. In some species, calcite c axes are perpendicular to the test surface; in others, axes are nearly tangent to the surface and oriented

in meridional fashion. Most families sampled are nearly homogeneous with respect to crystallographic orientation: each family exhibits either the tangential or perpendicular orientation but rarely both. Furthermore, the two preferred orientations appear to have evolved independently several times in echinoid history.

Two anomalous species, *Lytechinus variegatus* (Lamarck) and *Hemicentrotus pulcherrimus* (Barn.; A. Agassiz), have been studied in detail. Both forms show ontogenetic variation in orientation of c axes. In *H. pulcherrimus*, for example, plates near the peristome (oldest plates) have c axes perpendicular to the test surface, and successively younger plates have lower inclinations: the axes of the plates near the apical system (youngest plates) are inclined at about 45°.

The evolution of preferred crystallographic orientation may be related to echinoids' sensitivity to light. The "perpendicular" orientation should be best adapted to conditions of high light intensity (shallow, clear water). Among living echinoids, species that do not have this orientation characteristically cover themselves with debris to shield themselves from light.

DEVONIAN REEFS IN THE PAHRANAGAT RANGE, SOUTHEASTERN NEVADA

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Field work has brought to light definite similarities between the table and patch reefs of the Guilmette formation (lower–upper Devonian) in the Pahranagat Range and the intensively studied reefs of equivalent age in the subsurface of Alberta, Canada.

The Guilmette formation (2175–2475 feet) is divided into a lower biostromal shoal foundation member (628–810 feet) consisting of alternations of thin-bedded light dolomites and dark calcilutites. Algae and shelly facies fauna predominate. These units coalesce to form thick limestones and subdivide again into thin units laterally, but coalesce progressively vertically, to form a massive *in situ* algal biostrome 120–340 feet thick. Upon this foundation slightly to completely dolomitized coralline and calcareous-organic local bioherms developed.

The remainder of the Guilmette section consists of a heterogeneous sequence of biostromal algal-stromatoporoid calcilutites, dark dolomitized amphiporid biostromes, lenses of shallow-water fossiliferous limestones (brachiopods, gastropods, corals), deeper-water barren limestones, and 1- to 150-foot quartz sandstone units.

The widespread biostromal beds suggest lateral reef migration under changing eustatic levels and mildly unstable shelf conditions. Organisms are generally not mixed, and one type may constitute a complete bed. Study of additional well-distributed sections may demonstrate reef zonation.

Subdivision of the Guilmette above the lower foundation member is not possible because of the complex facies relationships reflecting progressive accumulation of interfingering organic shoals and and inter-reef channels.

Integrated lithofacies and biofacies analysis of the completely exposed Guilmette sections in the Pahranagat Range and surrounding areas will increase knowledge of Great Basin Devonian reef paleoecology.

TETRAHEDRAL ALUMINUM CONTENT OF MONTMORILLONITE

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Several X-ray-diffraction techniques and differential thermal analyses of a suite of Texas bentonites have shown that the bentonites are composed of different types of montmorillonite particles. The writer suggests that the differences result from the fact that some of the particles have a substantial amount of aluminum substituting for silicon in the tetrahedral positions of the clay structure, whereas other particles have relatively little substitution.

A series of tests or techniques that have been suggested to differentiate structures with high tetrahedral substitution from those with low tetrahedral substitution of aluminum for silicon have been intensively studied. These included: (1) potassium saturation with subsequent heating and glycerol solvation; (2) lithium saturation with subsequent heating and glycerol solvation; and (3) dehydroxylization temperatures during differential thermal analysis.

On the basis of the results from these studies, the samples could be divided into two groups. One group consists of samples that are composed of particles having a low degree of substitution. These samples dehydroxylate at approximately 700°C. The other group consists of samples that are composed of two phases: one has a small amount of substitution, and the other has a substantial amount of substitution. These samples dehydroxylate at 550°C. and 700°C. Size fractionation by centrifugation of the latter group of samples enabled a partial separation of the two phases.

PROGRESSIVE METAMORPHISM IN THE OTAGO SCHIST, EAST OTAGO, NEW ZEALAND

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Sixteen miles of nearly continuous exposures in the Brighton-Taieri Mouth area of East Otago, New Zealand, allows study of a series of rocks gradational from slightly recrystallized graywackes to completely recrystallized biotite schists. A broad syncline trends northwest at right angles to the coast, and the strata within the area are 7000 to 9000 feet thick. Metamorphism increases from southwest to northeast. Changes are indicated by both textural-structural and mineralogical criteria.

Textural-structural changes with increasing metamorphism are traced in rocks which were originally coarse-grained graywackes, using in slightly modified form the four "Subzones of the Chlorite Zone" (1, 2, 3, 4) defined by Turner and Hutton. Textural change is also indicated by the disappearance of recognizable clastic muscovite within Subzone Chlorite 3.

Mineralogical changes with increasing metamorphism are the disappearance of pumpellyite in favor of additional epidote (in Subzone Chlorite 3) and the appearance of biotite (in Subzone Chlorite 4). Below the biotite isograd the chief ferromagnesian mineral is stilpnomelane. Chlorite is rare except as an apparent retrograde product in the biotite zone. Stilpnomelane is also present in the biotite zone, but rarely in assemblages with biotite.

In view of the large metamorphic differences determined within a relatively thin stratigraphic sequence, serious doubt is thrown upon the load-metamorphism theory advocated for the Otago schist by Wellman and Grindley.

INVERTEBRATE FAUNA OF THE GOLCONDA FORMATION (MIDDLE CHESTER) OF INDIANA, WESTERN KENTUCKY, AND SOUTHERN ILLINOIS

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The Golconda fauna, comprising 67 species, is known from 45 collecting sites, of which 30 are in Indiana. Long-ranging forms dominate and include 18 brachiopod species, 14 species of *Pentremites*, and 12 distinct *Archimedes* shaft forms. Bryozoans are mainly fistuliporoids and stenoporids; *Fistulipora excellens* is the most common species. Infrabasal cones of the stemless crinoid *Agassizocrinus* locally are plentiful or absent.

Pterotocrinus wing plates are good horizon indicators for the middle (Fraileys) and upper (Haney) units of the formation. *Pterotocrinus capitalis*, *P. coronarius*, *P. armatus*, *P. abruptus*, and *Pentremites obesus* characterize the Fraileys of southeastern Illinois and northwestern Kentucky but were not found in the Indiana Golconda. *Pterotocrinus* cf. *P. armatus*, *P. lingulaformis*, *Stenoscisma explanatum*, and members of the *Pentremites pyriformis* group are faunal elements of the Haney in the Illinois-

Kentucky fluorspar district and the Golconda of Indiana. Shales in the basal Golconda in Martin County, Indiana, locally contain poorly preserved fenestellid fragments, *Archimedes* shafts, fragile compressed brachiopods, conulariids, and ostracodes but lack species restricted to the Fraileys.

Recent authors have correlated the entire Indiana Golconda with the Haney of the fluorspar district by physical stratigraphic methods. Paleontologic evidence is not strongly conclusive but tends to support this correlation. Lack of fossiliferous lower Golconda exposures in Illinois has impeded its paleontologic correlation with the Beech Creek limestone of Indiana.

FLUID INCLUSIONS AS SAMPLES OF THE ORE-FORMING FLUIDS

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Data from studies of fluid inclusions in transparent ore and gangue minerals, such as quartz, calcite, fluorite, and sphalerite, from hydrothermal ore deposits, have been examined critically for evidence regarding the heavy (ore) metal content of the ore-forming fluid. The following conclusions are reached:

(1) At least some inclusions in ore and gangue minerals, at the time of trapping, contained the identical fluid from which the ore and host minerals were precipitating, and which was saturated with respect to these minerals.

(2) These inclusions, in most cases, have not lost or gained appreciable quantities of material since being trapped.

(3) Simple calculations show that if decreasing temperature were a significant factor in causing precipitation of the ore minerals in the deposit, these should also precipitate from the fluid in the inclusions, upon cooling.

(4) Such precipitated mineral grains are very rarely seen, even in the larger inclusions.

(5) Although there are alternative explanations, the quantitative evidence supports the concept that the ore-forming fluids are exceedingly dilute in the ore metals—in the range of 0.001–0.01 gram per liter up to a maximum of perhaps 0.1 gram per liter.

(6) In spite of the low concentrations, these dilute solutions are still geologically reasonable.

ROLE OF MICROBIOLOGICAL PROCESSES IN THE FORMATION OF PEAT AND THEIR RELATIONSHIP TO COAL GENESIS

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The existence of a peat microflora has been questioned, but such a microflora does exist and consists of bacteria, fungi, and actinomycetes, which are active in the decomposition of plant residues. The microfloras of the different peats vary in accord with conditions of acidity or alkalinity and the availability of nitrogen and oxygen.

These conditions determine the course of microbial attack on plant debris and, depending on the type of plant materials undergoing attack, lead to variations in the peat formed. It has been postulated that differences in the biochemical alteration of plant residues are responsible for formation of the different ranks of coal. Long periods of slow microbial decomposition of plant material under anaerobic conditions would lead to a product low in nitrogen and oxygen and thus toward formation of high-rank coals. Conversely, aerobic oxidative processes involving less nitrogen loss from the system and resulting in a product richer in oxygen may precede formation of the lignites and brown coals. Data on the decomposition of various plant materials, such as oak leaves and sphagnum moss, tend to confirm these suppositions, as do data on the differential decomposition of lignin. The role of the various groups of micro-organisms active in plant decay and responsible for these phenomena is discussed. Both nitrogen and oxygen are important limiting factors in the decomposition processes; in-

availability of nitrogen almost halts decomposition, and the products of lignin attack depend directly on conditions of oxygen tension.

TRACE ELEMENTS IN SULFIDE MINERALS FROM THE CENTRAL DISTRICT, NEW MEXICO, AND THE BINGHAM DISTRICT, UTAH

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Chalcopyrite and sphalerite (373 samples) from the Central district, New Mexico, and the Bingham district, Utah, have been analyzed spectrographically for trace-element content. Chalcopyrite and sphalerite from both districts can be divided into two or more groups of differing trace-element content and location within the districts. Geologic and mineralogic differences exist between the ores of different groups in some cases, but enough similarities of host rocks and mineral associations exist to allow the conclusion that temperature and other conditions at the time and site of deposition are not the principal cause of the grouping, but that differences of trace-element content probably existed in the ore fluids before they reached the site of deposition.

Within the main sphalerite group in the Central district, a poorly developed lateral zoning away from the Hanover-Fierro and Santa Rita intrusive rocks exists. Iron, manganese, and cobalt in the sphalerite decrease away from the intrusive rocks, and gallium increases. The lead-zinc ratio and the silver content of the ores show similar zoning. Less well-defined zoning is found in chalcopyrite from the Central district and sphalerite from Bingham. Either temperature gradients or progressive concurrent changes in the composition of the ore fluid and the site of deposition are possible causes of the zoning.

The above effects account for only part of the trace-element variability within the districts. Local poorly understood variations in the mineralizing process are apparently responsible for much of the variability found.

SUBSOLIDUS RELATIONS ON THE JOIN $CaMg(CO_3)_2$-$CaFe(CO_3)_2$ OF THE SYSTEM $CaCO_3$-$MgCO_3$-$FeCO_3$

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Subsolidus relations on the join $CaMg(CO_3)_2$—$CaFe(CO_3)_2$ have been investigated in the temperature range 350–550°C. and at oxygen pressures sufficiently low, and carbon dioxide pressures sufficiently high, to prevent the dissociation of the carbonates. At 450°C. the join is binary from $CaMg(CO_3)_2$ to 75 mole % $CaFe(CO_3)_2$ (ferrodolomite). Compositions within this range yield a single phase; an ordered dolomite-ferrodolomite solid solution. Dolomite solid solutions, extending from 33 to 75 mole % ferrodolomite are often referred to as ankerites. At 75 mole % $CaFe(CO_3)_2$ and 450°C. the one-phase field terminates in a three-phase triangle in the system $CaCO_3$—$MgCO_3$—$FeCO_3$. Compositions higher in iron, at this temperature, yield three phases, calcite and siderite solid solutions, and ankerite. At 85 mole % $CaFe(CO_3)_2$ and 450°C. the last trace of ankerite disappears, and the join intersects the two-phase field of calcite and siderite solid solutions that extends to the end member $CaFe(CO_3)_2$.

As the temperature is increased from 350 to 550°C. the three-phase space in the ternary system swings toward the binary join $CaCO_3$—$FeCO_3$ with the result that along the dolomite-ferrodolomite join the one-phase field extends further toward ferrodolomite. This indicates that at sufficiently high temperatures ferrodolomite may be stable. Since the composition of the ankerite in equilibrium with calcite and siderite is temperature-dependent, a possible application in geothermometry is suggested.

CONTAMINATION-REACTION RULES

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A graphical thermodynamic method is used to derive six contamination-reaction rules. They relate the order of disappearance of phase assemblages to variations of temperature, pressure, and activities of mobile components when compositions change in a particular way.

Thus:

Referring to a particular horizontal row below, let quantities A remain constant. Let a given reactant phase assemblage disappear reversibly with B variation in C to form a product assemblage at a given value of C, C_1. Then the compositional change represented by additional presence of a phase, compatible with the reactant assemblage and incompatible with the product assemblage, causes a shift, D (to C_2), in the condition for reversible disappearance of the contaminated reactant assemblage.

	A	B	C	D
(1)	$n_a, \cdots, n_e; a_f, \cdots, a_k; P$	$+$	T	$T_2 < T_1$
(2)	$n_a, \cdots, n_e; a_f, \cdots, a_k; P$	$-$	T	$T_2 > T_1$
(3)	$n_a, \cdots, n_e; a_f, \cdots, a_k; T$	$+$	P	$P_2 < P_1$
(4)	$n_a, \cdots, n_e; a_f, \cdots, a_k; T$	$-$	P	$P_2 > P_1$
(5)	$n_a, \cdots, n_e; a_a, \cdots, a_k; T; P$	$+$	a_f	$a_{f2} < a_{f1}$
(6)	$n_a, \cdots, n_e; a_a, \cdots, a_k; T; P$	$-$	a_f	$a_{f2} > a_{f1}$

Notation; n: number of moles; P: pressure; T: temperature; a: activity (related to pure component at P and T in question); subscripts a to e: fixed components; subscripts f to k: mobile components

Application is based on data readily ascertained in field and laboratory. The rules provide one possible analytical basis for the subdivision and arrangement of the mineral facies of rocks. They also emphasize the need for caution in applying results of experimental study of "clean" compositional systems to petrogenetic interpretation.

STRATIGRAPHY OF THE TYPE WOLFCAMP SERIES (PERMIAN), GLASS MOUNTAINS, TEXAS

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The type Wolfcamp series in the Glass Mountains, Texas, has long been recognized as an excellent marine stratigraphic sequence containing abundant, varied faunas of early Permian age. It is used as a standard section for North America although hitherto poorly known. Stratigraphic relations and fusulinid faunas show that the Wolfcamp series is a sequence of dissimilar rock facies with a major unconformity near its middle.

In the Wolf Camp Hills, the base of the Wolfcamp series (base of the Permian in this area) is taken at the base of the shale and limestone strata unconformably overlying the "Grey limestone member" of King (1931; 1937) which, on the basis of its fusulinid fauna, is considered of Virgil age. Strata equivalent in age to these early Wolfcampian shale and limestone beds are known elsewhere only at Gap Tank, Hess ranch horst, and in folded and faulted strata in the Marathon orogenic belt 7 miles northwest of Marathon. Overlying this sequence unconformably are the upper strata of the Wolfcamp series, which also have a *Pseudoschwagerina* fauna, exposed in a belt from Dugout Mountain in the southwest to Gap Tank and beyond in the northeast. The western exposures of these upper Wolfcampian strata can be traced eastward into the lower 200–300 feet of the Hess facies of the Leonard formation of King (1937). Throughout the area the Leonard formation (redefined) unconformably overlies the Wolfcamp series with local angular discordance.

CRYSTAL STRUCTURE OF ABERNATHYITE

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As part of a systematic study of minerals of the torbernite group, crystals of abernathyite, obtained from the original specimen described by Thompson, Ingram, and Gross (1956) as a potassium uranyl arsenate ($KUO_2AsO_4 \cdot 4H_2O$), have been examined in detail by X-ray-diffraction techniques.

The mineral occurs as transparent, yellow, thick tabular crystals belonging to the tetragonal system. The tablets are flattened parallel to (001) and are bounded by the form {110}. Optically the mineral is uniaxial negative, $\epsilon = 1.570 \pm 0.003$, $\omega = 1.608 \pm 0.003$. The space group is $P4/ncc(D_{4h}^9)$, $a = 7.18 \pm 0.01$, $c = 18.13 \pm 0.02$ Å, $Z = 4$. Optical and X-ray-powder data of the material studied correspond to the properties reported in the original description.

The crystal structure of abernathyite has been determined by X-ray-diffraction methods. Intensity data were obtained from Buerger precession photographs of the (*hk*0), (*hk*1), and (0*kl*) nets. Electron-density maps and heavy-atom subtraction maps on (100) and (001) resolved all uranium, arsenic, and oxygen atoms.

Abernathyite has the meta-autunite structure with alternate sheets of composition $[UO_2AsO_4]_n^{-n}$ displaced by the vector $[\frac{1}{2}\frac{1}{2}0]$. Between the uranyl ions of successive sheets lie groups of four water molecules, hydrogen-bonded to form squares. Each water molecule of the square is hydrogen-bonded to one water molecule of an adjacent square and to an arsenate oxygen. Potassium can be accounted for only by random replacement of one of the four H_2O molecules. Thus, the correct formula is probably $KUO_2AsO_4 \cdot 3H_2O$.

TRIDYMITE—CRISTOBALITE RELATIONS AND STABLE SOLID SOLUTIONS

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Experiments in sealed platinum containers have been directed toward establishing the extent and stability of solid solutions in tridymite-M, tridymite-S, and cristobalite. Not only can cristobalite solid solutions be crystallized from gels and glasses, but pure SiO_2 3C-cristobalite will react with $Na^+ + Al^{3+}$ at 1400°C. to give solid solutions having enlarged unit cells and containing about 2 mole per cent $NaAlO_2$. Also admitted into the lattice are $(K^+ + Al^{3+})$ and $(Li^+ + Al^{3+})$. The data point to the lowering of the "1470°" inversion in the $NaAlO_2$-SiO_2 system. The effects of LiF, Li_2WO_4, Na_2WO_4, K_2WO_4, $Na_2Si_2O_5$, and $K_2Si_4O_9$ have also been studied. With the exception of Li_2WO_4, the other fluxes yield tridymites below and cristobalites above 1470 ± 30°C. X-ray spacings of the cristobalites are not altered more than ±0.02° at 36.1° 2θ (CuKα) by any of these fluxes. The data lend unexpected support to the validity of the 1470° inversion temperature but do not establish it.

ZEOLITE STUDIES. II: STABILITY OF THE LITHIUM ZEOLITES

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Starting with gels and glasses, not impossible compatibility triangles have been determined for the system Li_2O—Al_2O_3—SiO_2—H_2O from 200–600°C at water pressures up to 4000 bars. Three hydrates, all probably zeolitic, are known in the system; natural bikitaite ($Li_2O \cdot Al_2O_3 \cdot 4SiO_2 \cdot 2H_2O$), LASH-I (Barrer's "A", $Li_2O \cdot Al_2O_3 \cdot 2SiO_2 \cdot 8H_2O$(?)), and LASH-II (Barrer's "H", $Li_2O \cdot Al_2O_3 \cdot 8SiO_2 \cdot 10H_2O$).

Of these bikitaite could not be synthesized under any p-t conditions, in the above range, even with variations in pH and seeding.

The following reactions take place:

$$\text{LASH-I} \xrightarrow[1000 \text{ atm.}]{285^\circ} \alpha\text{-Eucryptite } (+ \beta \text{ euc.}) + H_2O$$

$$\text{Bikitaite} \xrightarrow[1000 \text{ atm.}]{420^\circ} \beta \text{ spodumene} + \alpha \text{ eucryptite (no petalite observed)}$$

$$\text{LASH-II} \xrightarrow[1000 \text{ atm.}]{465^\circ} \text{Petalite} + H_2O.$$

Bikitaite's structural predisposition for β-spodumene is also shown by the facts that it will decompose "dry" at 400°C. to give β-spodumene; α-spodumene was not encountered in any run; while in many runs obviously metastable assemblages are obtained.

GEOCHRONOLOGY OF LATE CENOZOIC VOLCANISM, SAN FRANCISCO VOLCANIC FIELD, ARIZONA

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Rhyolitic tuff beds occur in northern Arizona in the Bidahochi beds (early to middle Pliocene), beneath the oldest lavas in the San Francisco field, and in the Hickey formation (Lehner, 1958) of the Upper Verde Valley. Most outcrops were correlated by field study and trace-element and thermoluminescence work. The lowest beds thicken and coarsen toward the 1200-foot tuff section of 13-mile rock southeast of Camp Verde. This section is part of a lava dam which at one time cut off the Verde River and caused deposition of the Verde lake beds. Potassium-argon dating (Arizona-Lamont) of biotite from the 13-mile-rock section gives an age of 14.3 m.y. for the tuff blanket which underlies the volcanic fields mentioned above. This date compares well with the fossil date on the lower Bidahochi beds (Williams, 1936; Lance, 1954). It is suggested that Hickey and older San Francisco lavas and Bidahochi volcanic rocks are of corresponding age, and that the Verde lake beds were formed since early Pliocene time. Basin and Range block faulting and beginning of plateau uplift, canyon cutting, and volcanism near the plateau rim were events in late Miocene–early Pliocene time.

The youngest basaltic lavas were studied by thermoluminescence at the University of California, Los Angeles. Using one known tree-ring date (Smiley, 1955), a decay curve was constructed, and lava flows up to 35,000 years were placed in chronological order. Up to that date there is agreement with field evidence (erosion state, superposition), and the 35,000-year date is checked by glacial evidence, which sets early and late Wisconsin age as upper and lower limits.

SYMBOLS FOR GRAPHIC REPRESENTATION OF DIRECTIONAL SEDIMENTARY STRUCTURES

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Many kinds of sedimentary structures have been recorded that indicate the direction of latest current movement or result from downslope creep or slumping of unconsolidated sediments. Such paleocurrent and paleoslope indicators provide valuable quantitative paleogeographic data.

Directional structures occur in sediments deposited in many environments; they are most abundant in sand-sized sediments or in sequences where sand- and silt-to-clay sized sediments are repeatedly interbedded.

Each symbol presented portrays both the sedimentary structure and its directional indication; the symbols are designed for use on large-scale graphic columnar sections where the symbol may be

placed in the margin next to the bed in which the structure occurs. A glance at columnar sections on which symbols have been plotted immediately conveys the distribution of the structures and the scatter of their orientation directions. Systematic plotting of these structures on a detailed stratigraphic base offers possibilities for determining mutual relationships between the structures and for locating distinctive key beds in what may otherwise appear to be a uniform section. This stratigraphic approach to the study of directional structures may be more valuable than the single-station-direction approach that has been used most commonly to date.

ELECTROCHEMICAL STUDY OF OXIDATION OF SULFIDE MINERALS AT 25°C.

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Measurements of the single electrode potentials of sulfide minerals backed with a basic understanding of their electrode behavior make it possible to clarify their oxidation or reduction mechanisms. The electrode potential of a sulfide mineral is controlled by the first-step reaction of the oxidation mechanism for the sulfide in an oxidizing solution and by that of the reduction mechanism in a reducing solution. Sulfides of copper, lead, silver, iron, and zinc were studied. The results indicate that the direct oxidation of a simple sulfide mineral is a process in which the metal atoms move into the surrounding solution to become aqueous cations, accompanied by a stepwise decrease in the metal to sulfur ratio of the remaining solid phase. When solid sulfur is finally left over, it undergoes a series of reactions to be oxidized to sulfate ion. In case of reduction, sulfur atoms move out into the solution to become aqueous sulfide ions with a stepwise increase in the metal to sulfur ratio of the solid phase. To illustrate, the oxidation of chalcocite proceeds as:

$$(Cu_2S) \rightarrow \tfrac{1}{8}(Cu_9S_8 + Cu^{++})? \rightarrow (CuS + Cu^{++}) \rightarrow (S + 2Cu^{++})$$

The path of the stepwise oxidation is not necessarily the same as that of the stepwise reduction for a metal-sulfur system. In the case of disulfides of iron, namely pyrite and marcasite, ferrous ions and S_2 molecules appear to be released into the solution simultaneously upon oxidation.

CHLORINE-36 RADIOACTIVITY IN RAIN*

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Cosmic rays and nuclear explosions are adding radioactivity to the atmosphere which is then removed by rainfall. The investigation of these activities furnishes a means of obtaining new information of significance in geological problems. Chlorine-36 is a useful isotope for such an investigation as it has a long half life, 300,000 years, and is very soluble in water. Two rains collected in the summer of 1957 were found to contain 2.0 and 8.0 d/min-g Cl. These levels of activity are several orders of magnitude larger than expected from cosmic-ray production and are probably produced by neutron irradiation of sea spray in oceanic nuclear explosions. Water taken from below the water table in Long Island contains 0.68 d/m-g Cl of chlorine-36 activity. This value is lower than that in the rain, possibly because the mean residence time of Long Island ground water is larger than the time during which chlorine-36 has been added. This would indicate a mean residence time in excess of 10 years. Water taken from a Vermont stream contained 0.37 d/m-g Cl of chlorine-36 activity. Possibly the Vermont stream activity is below the rain value because of the dilution or exchange of the chloride in rain with mineral chloride. One would then estimate that most of the chloride in the stream is of mineral origin.

* Research performed under the auspices of the U. S. Atomic Energy Commission.

JOIN PROTOENSTATITE-DIOPSIDE-ALBITE IN THE SYSTEM FORSTERITE-DIOPSIDE-SILICA-ALBITE

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The join protoenstatite-diopside-albite roughly bisects the regular tetrahedron used to represent the system forsterite-diopside-silica-albite. Liquidus data presented for the join show that it cuts the primary phase volumes of forsterite, diopsidic pyroxene, and soda-rich plagioclase. For some compositions and temperatures two conjugate pyroxenes coexist with liquid or with liquid and forsterite crystals. The crystallization relations are shown by means of a selected series of isothermal planes at 1350°, 1300°, 1250°, 1200°, and 1150°C.

SANDSTONE PIPES OF THE LAGUNA AREA, NEW MEXICO

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Many hundreds of cylindrical sandstone columns—termed sandstone pipes—are exposed in the Laguna area. They cut nearly horizontal strata of the Summerville, Bluff, and Morrison formations of Jurassic age.

The pipes range from a few feet to a few hundreds of feet high, and a few inches to 150 feet wide. Comparative petrographic studies of the material in the pipes and of the enclosing strata show that each pipe is composed largely of reworked massive subarkosic sandstone derived from the uppermost units cut by the pipe. In places a breccialike texture is present, with sandstone or mudstone fragments embedded in a matrix of similar lithology. The wall rocks sag inwardly around the pipes, and the pipes are bounded by one or more ring faults with downward displacement on the inner side. The bottoms of the pipes, rarely exposed, are in sharp contact with little-deformed underlying beds. The pipes commonly flare outward at their tops, near the middle of a sandstone unit, and are buried by successively less deformed beds.

Most pipes are in belts along gentle structural depressions of Jurassic age; some are associated with local thinning or absence of an underlying gypsum unit.

The pipes originated during sedimentation of the uppermost units that contain them and involve sediments that were then poorly consolidated. They probably formed in part by gravitational foundering of sand into mud and locally by collapse resulting from the removal of underlying gypsum. Contemporaneous structural depressions apparently localized both processes.

DISTRIBUTION OF MODERN SEDIMENTS IN THE PERU-CHILE TRENCH

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The modal compositions of 30 core samples collected by ATLANTIS from the Peru-Chile Trench have been determined by quantitative X-ray techniques. The cores were collected between Mollendo, Peru, and Punta Plata, Chile, in an area about 200 miles wide and elongate parallel to the axis of the trench. The distribution of mineral phases within this area appears to be directly related to provenance geology. The observed correlation is particularly good for quartz, potassium feldspar, plagioclase, hornblende, and chlorite. The effects of local factors controlling sedimentation (winds, currents, bottom topography) may be recognized, but the over-all distribution is sufficiently systematic to permit the formulation of a generalized pattern of sedimentation.

More than half of each sample is amorphous to X rays and consists largely of volcanic glass. Identi-

fiable ash beds are all very thin (1–10 mm), and no thick ash accumulation comparable with that described by workers in nearby areas of the Pacific was found.

The sediment mineralogy shows rapid lateral variation, and correlation of discrete beds from core to core appears almost impossible. Two ash falls (?) are tentatively correlated between cores, however, on the basis of their mineralogy.

Mineralogical changes within a single core are less marked, though many sharp breaks are observed in the near-shore samples. These mineralogical variations are in many cases accompanied by textural changes and are believed to reflect deposition from turbidity currents or ash falls.

GEOLOGIC SIGNIFICANCE OF AN AERORADIOACTIVITY MAP OF PART OF SOUTH CAROLINA AND GEORGIA

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A recent air-borne radiological survey in South Carolina and Georgia indicates that several geologic units may be distinguished by their characteristic radioactivity.

The survey of 10,000 square miles near Augusta, Georgia, was made by the U. S. Geological Survey for the U. S. Atomic Energy Commission. Continuous radioactivity profiles were obtained with scintillation counting equipment along parallel northwest-southeast flights made at 1-mile intervals approximately 500 feet above the ground. A map of aeroradioactivity units prepared from the profiles has been compared with the areal geology.

About 2000 square miles of the Piedmont province, mantled partly by thick saprolite, is included in the area. Three types of bedrock are present: slate and schist of the Carolina Slate Belt; a metamorphic complex of schist, gneiss, and granite; and plutons of granite and porphyritic granite. Migmatized zones within slate, granite, and gneiss are generally the most radioactive. Several units in the Piedmont, irrespective of weathering, may be mapped by their distinctive radioactivity.

The Coastal Plain, consisting of several sedimentary units of Late Cretaceous to Quaternary age, constitutes the rest of the area surveyed. Poorly consolidated sand predominates, but gravel, clay, marl, and limestone are also present. In general the radioactivity of the Coastal Plain is lower than that of the Piedmont. Most of the radioactivity highs in the Coastal Plain occur near the base of the sedimentary section and seem to be related to erosion of nearby granite and gneiss.

PROPOSED RULE OF CRYSTAL HABIT

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A crystal model is constructed in momentum space by plotting the surface through the points representing the vectors of waves of maximum momentum that can propagate through the crystal. The surface is a polyhedron enclosing all wave vectors in the crystal's spectrum, $\bar{q}_i < \pi/\bar{a}$, where $\bar{a}$ is the smallest periodicity in the direction of the wave vector. To a given row of N points $\bar{a}$ apart in the direct structure, there corresponds a row of N points $\pi/N\bar{a}$ apart in the polyhedron. The polyhedron is the zone of all waves that may propagate through the crystal. The dimensions of the row in direct space are proportional to the density of the row in the zone. From the argument of (1) symmetry, and (2) thermodynamic equilibrium, the point gas formed within the zone when additional points are added in the process of crystal growth should be perfectly elastic. The ideal crystal takes the form of the zone, or: *the equilibrium form of a crystal is the form of the envelope of the spectrum of vibrational waves which propagate through the crystal.* The Law of Donnay and Harker and the law of Bravais are contained in the rule. The form of the envelope is a function of the structure, of the force constants, and of the composition of the crystal.

AQUIFERS IN MELTWATER CHANNELS ALONG THE SOUTHWEST FLANK OF THE DES MOINES LOBE, LYON COUNTY, SOUTHWESTERN MINNESOTA

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During the Cary and Mankato substages of Wisconsin glaciation the Des Moines lobe advanced southeasterly through the broad lowland of the Minnesota River valley of southwestern Minnesota and thence southward to central Iowa.

Among the most prominent topographic features in Lyon County, Minnesota, are five northwest-trending end moraines, two of which are associated with and parallel to belts of surficial outwash which are approximately half a mile to a mile wide. Test drilling indicated that one of the belts of outwash is underlain by a complex system of buried meltwater channels. The other is the upper part of a series of deposits in an incised channel. The channels are filled with till, glaciolacustrine deposits, and outwash which includes permeable deposits of water-bearing sand and gravel.

Associated with the surficial meltwater channels is a pronounced northwest-trending linear drainage pattern. By studying the lineation of streams and lakes, analyzing the available water-well data, and drilling test holes, several elongate deposits of buried outwash having little or no topographic expression were located. The long axes of the deposits are generally parallel to the lineation of the drainage and the end moraines.

The meltwater channels in Lyon County trend northwest-southeast because the flank of the ice sheet was confined by a landmass that sloped to the northeast. By studying their local occurrence, it is probable that other buried channels can be located and additional ground-water supplies developed elsewhere along the southwest flank of the Des Moines lobe.

SARGASSOID MICROFOSSIL ASSEMBLAGE FROM BLACK SHALE OF EARLY PALEOZOIC AGE IN FLORIDA AND GEORGIA

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Special preparation methods have yielded rich assemblages from deep cores of dark fissile shale of Ordovician and Silurian age. These include chitinozoans of the families Lagenochitinidae, Desmochitinidae, and Pterochitinidae; hystrichosphaerids; and numerous sporelike microfossils. Large sporelike microfossils that have a "silty" texture may represent chitinous envelopes of testacean protozoans. Smaller types of spores are commonly more abundant. They may represent algae that also contributed the abundant humic debris of these deposits. Some of the chitinozoans show internal structures.

Fissility of the shale is principally a result of diagenetic compaction; nearly all fossil structures are notably compressed. Silt-sized rounded quartz grains, microcrystals and aggregates of pyrite, tiny flakes of mica, microscopic dolomite(?) rhombs, vermiform aggregates of kaolinite, and probably other clay minerals contribute, with humic matter, to the matrix. Pyrite and abundant carbonaceous material signify deposition in a euxinic environment. The fossils, however, probably represent a sargassoid biocenosis, similar to those postulated by Ruedemann. The biota evidently flourished in marine surface waters, and individuals were killed whenever they sank into toxic, unaerated depths.

Similar spore and hystrichosphaerid assemblages have been described from strata of Early Paleozoic age (and possibly late Proterozoic) of Eastern Asia, the Ural Mountains, and Karelia in the Soviet Union. Chitinozoans have previously been recovered principally from carbonate solution residues of Early Paleozoic age in the Baltic area, in western Europe, and in the Devonian of cen-

tral United States. Both euxinic and carbonate deposits may contain the remains of sargassoid assemblages.

STABILITY OF Mg-CORDIERITE

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The stability limits of the pure magnesium end member of cordierite have been determined at 1000, 2000, 5000, and 10,000 bars water pressure. The breakdown products below temperatures of 450°-525°C. at pressures up to 5000 bars are chlorite (amesite) + pyrophyllite or chlorite + montmorillonite or montmorillonite solid solution only at successively lower temperatures. At 10,000 bars and 685°C. cordierite breaks down into chlorite and metastable quartz + corundum (= sillimanite).

The incongruent melting of dry Mg-cordierite at atmospheric pressure into mullite + liquid takes place at 1465°C. At 2000 bars and 1225°C. cordierite melts incongruently to mullite + spinel + liquid; at 5000 bars, 1090°, to spinel + sapphirine + liquid; at 10,000 bars, 960°, to sapphirine + liquid. The slopes of the upper and lower stability curves of cordierite indicate that at water pressures higher than approximately 13,000 bars cordierite will not be stable.

Cordierites prepared hydrothermally ($n_m \approx 1.540$) differ in mean refractive index from those made in the dry way ($n_m \approx 1.522$). This change is independent of the structural state (cordierite-indialite transition) and is believed to be due to variable amounts of water contained in the cordierite structure. The stable polymorphic form of Mg-cordierite throughout its stability field up to the beginning of melting was found to be the orthorhombic (pseudohexagonal) low-temperature form.

Anhydrous cordierites held in a water-free environment at 10,000 bars above 1000°C. gradually break down first into sillimanite + quartz + enstatite and sapphirine + quartz at still higher temperature. These reactions become more sluggish as the temperature decreases.

POST-CHELTENHAM DESMOINESIAN SEDIMENTATION IN THE COLUMBIA-HANNIBAL REGION, MISSOURI*

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The Pennsylvanian post-Cheltenham Desmoinesian beds of the Columbia-Hannibal region occupy a broad, shallow, northwest-trending syncline bordered on three sides by major tectonic highs: the Lincoln-Cap au Gres anticline, the Ozark uplift, and the Saline County arch. These were barriers to sedimentation throughout much of earlier Desmoinesian time. The major syncline is divided into small depositional depressions by a series of minor tectonic highs. The most prominent of these folds conform to the structural grain of the region. The small depressions are further subdivided by a secondary series of minor highs normal to the structural grain.

The following three factors were the most significant influences on the sedimentation of the Pennsylvanian: (1) The region was generally high and tilted to the northwest along the plunge of the major syncline. Although locally restricted by some of the minor tectonic highs, younger cycles overlap older ones from northwest to southeast. (2) The region did not subside sufficiently during some cycles for marine invasion, and, as a result, several cyclic sequences are restricted to underclay and coal beds or to underclay only. (3) The most nearly complete cycles are developed in the minor depressions. Many of the lithologic units thin rapidly and wedge out on the minor tectonic highs bordering the depressions.

* With permission of the State Geologist of Missouri

PRE-MARMATON PENNSYLVANIAN DEPOSITS OF THE FOREST CITY BASIN, MISSOURI*

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The succession of pre-Marmaton beds in the Forest City Basin of northwestern Missouri, southwestern Iowa, northeastern Kansas, and southeastern Nebraska includes Desmoinesian beds similar in lithology and thickness to those of the outcrop area of western Missouri, southeastern Kansas, and northeastern Oklahoma. Similarity is sufficiently close to permit the formational classification of the outcrop area of the northern midcontinent to be applied to these strata. They are also so similar to beds of equivalent age in western Illinois that the northern midcontinent and the Illinois basin are judged to have been connected through the Forest City Basin in pre-Marmaton Desmoinesian time. All are cyclic shelf deposits.

The oldest Desmoinesian rocks are separated from the Mississippian by a succession of beds which are more than 300 feet thick in the deepest part of the basin. These strata occupy the position of, and resemble lithologically, beds of Atokan age identified elsewhere in Missouri, and they are assigned to this series. The Forest City Basin deposits of this age are much thicker than those known elsewhere in the shelf area of the northern midcontinent. Unlike Desmoinesian sediments, they appear to lack a northern connection with the Eastern Interior basin.

GRAVITY INVESTIGATION ACROSS THE FOLDED APPALACHIAN MOUNTAINS IN SOUTHWEST VIRGINIA

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About 600 gravity determinations have been made in a belt across the complexly folded and faulted Appalachian Mountains west of Roanoke, Virginia. The area extends from Long. 80°15′W. to 81°15′W. and Lat. 37°00′N. to 37°30′N.

The area investigated includes Precambrian(?) metamorphic and igneous rocks of the Blue Ridge Province and Paleozoic rocks of the Valley and Ridge Province.

Regional Bouguer anomalies, computed for a density of 2.7, trend about N.40°E., whereas the Appalachian structures trend about N.70°E. The anomalies in some instances can be correlated with the main structural features that include several major faults, synclines, and anticlines. The southeast limb of the major synclinal basin is thrust-faulted, and the gravity data suggest that the basin consist of two synclines, one thrust over the other.

Anomalies range from −73 to −88 mgals in the main synclinal basin and from −65 to −68 mgals in a depression along the main anticlinal area. Possibly basement structure or buried structural features due to overthrusting cause many of the anomalies that cannot be related to surface features.

SOLUBILITY OF CALCITE IN WATER BETWEEN 100°C. AND 200°C.

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Solubility of calcite in water has been studied as a function of temperature and CO_2 pressure between 100°C. and 200°C. and at CO_2 pressures between 4 and 250 atmospheres. Work is in progress at higher and lower temperatures and pressures. Large crystals of clear calcite were covered with double distilled water in a teflon test tube. The test tube was placed in a stainless-steel bomb fitted with a head that permitted sampling of the aqueous phase at the operating temperature and pressure.

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A large oil bath was used to heat the bomb. After equilibrium had been established, the liquid phase was sampled, and the calcium content of the sample was determined by means of an EDTA titration.

Our results agree with those of Miller (1952) only in the low-pressure region. It seems certain that Miller's results at pressures in excess of 10 bars are in error because of precipitation of $CaCO_3$ during quenching. There is good agreement between our data and those of Ellis (1959) except at 150°C. and 62 bars. All these results confirm that the solubility of calcite increases rapidly with increasing CO_2 pressure and decreases rapidly with increasing temperature.

STUDY OF SPECIATION (SUBSPECIATION) IN THE PENNSYLVANIAN OSTRACODE *BAIRDIA OKLAHOMAENSIS* S. L. FROM INDIANA*

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The ostracode *Bairdia oklahomaensis* s. l. is especially common among Pennsylvanian faunas of the Illinois Basin and the Midcontinent, but many concepts under at least four names have been applied to this species. Earlier confusion resulting from the traditional typological approach to *Bairdia* does not permit us to accept safely any concept except the all-inclusive one. The species therefore had been assigned a very long range, Morrow into Missouri, and had little or no stratigraphic value.

The triangular graph is a useful tool for the interpretation of a quantitative study of 12 populations of *B. oklahomaensis* s. l. from throughout the vertical and lateral range of this species in Indiana. Vertical speciation occurred, so that *B. oklahomaensis* s. s. and *B. dornickhillensis* are recognized separately with respective ages of post-Atoka and pre-Des Moines and with further refinements in each of their stratigraphic ranges. *B. auricula* and *B. seminalis* (Payne only) should be considered as synonyms of *B. oklahomaensis* s. s. Geographic speciation or subspeciation apparently did not occur within the broader concept of the species. The triangular graph shows further that the considerably different mean sizes among the several populations are of no genetic or taxonomic significance.

The ontogeny of *B. oklahomaensis*, with nine molt stages, does not differ importantly from that of modern species of *Bairdia*. The modern name *Nesidea*, substituted in some cases for *Bairdia*, should be considered as a synonym.

PHASE STUDIES IN THE Fe-RICH CARBONATES OF THE BUNKER HILL MINE, IDAHO

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The Bunker Hill mine lies within the Coeur d'Alene district of northern Idaho. Both the mine and the district are well-known for the association of iron carbonate minerals with sulfide ore bodies of lead, silver, and zinc. Host rocks of the mine are Revett quartzites and St. Regis argillites of the Precambrian Belt series. The carbonate minerals—siderite, ankerite, and calcite—occur singly or in the pairs siderite-ankerite and ankerite-calcite. Compositions, determined from 100 chemical analyses of gangue and wall rock carbonates, are:

siderite, $(Fe_{.75-.85}Mn_{.06-.10}Mg_{.06-.10}Ca_{.02-.06})CO_3$
ankerite, $Ca_{1.00-1.12}(Fe_{.50-.70}Mg_{.20-.28}Mn_{.06-.12})(CO_3)_2$
calcite, $(Ca_{.96-.97}Fe_{.016-.024}Mn_{.008-.015}Mg_{.004-.006})CO_3$.

The distribution of the carbonates was determined for 350 samples, including samples from ore-bearing structures and wall rock. Siderite is most abundant in and near ore-bearing structures, ankerite away from these structures, and calcite no closer than 200 feet from ore-bearing structures.

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The writer proposes that this distribution resulted from hydrothermal differentiation during mineralization. Consideration of aqueous carbonate systems, on the basis of general principles of heterogeneous equilibria, suggests the possibility of zoning of the carbonate minerals in veins and wall rock, with respect to a point of initial precipitation in the vein system, in the order (1) siderite, (2) siderite + ankerite, (3) ankerite, (4) ankerite + calcite, and (5) calcite. This pattern is observed in some sections of wall rock in the mine. The two most calcic zones, however, are not represented in ore-bearing structures.

GEOCHEMISTRY OF URANIUM IN PHOSPHORITES AND BLACK SHALES OF THE PHOSPHORIA FORMATION (PERMIAN)

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Uranium in the Phosphoria formation of Permian age in the western phosphate field occurs mostly in phosphorite and in part in black shale. The quantity of uranium, however, in some of the phosphorite and most of the black shale of the formation is negligible.

The immediate source of the uranium in the Phosphoria formation was probably the ocean. Geochemical considerations show that the pH and Eh control the oxidation states of the uranium and the formation of complex ions of both four-valent and six-valent uranium. In general the lower the pH and Eh, the more favorable the environment is for uranium precipitation. These theoretic considerations generally are confirmed by the distribution of uranium in the rocks.

Uranium in phosphatic sedimentary rocks occurs as adsorbed uranyl ion and as U^{+4} substitutions in the apatite lattice. The phosphatic rocks of the formation are classified according to the Eh and pH of their depositional environment, and their uranium contents are statistically compared. This analysis shows that phosphatic sediments that were deposited in an environment of low Eh are rich in uranium, whereas phosphatic sediments deposited in an environment of high Eh are poor in uranium. The pH of the environment where apatite is stable apparently has no effect on the concentration of uranium.

Few data are available on the mode of occurrence of uranium in black shale, but chemical and stratigraphic considerations indicate that possibly the uranium is deposited as disseminated UO_2 in a reducing acid depositional environment.

STABILITY OF TALWEG IN NATURAL CHANNELS

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Small-scale models demonstrate that the talweg pattern in curved channels (bends) is more regular and predictable, hence more stable in a special sense, than in straight channels. Doubts about the reliability of these findings from small-scale models are dispelled by identical conclusions deduced from observations on natural streams. A short-radius bend exhibits a more regular talweg than a long-radius bend. Investigations of river reaches point to a relationship between channel curvature and bar (or talweg) migration. A succession of bends (S-shaped channels) also influences the talweg behavior and can even induce a quasi-permanent talweg position. The behavior of the bed load is a clue to the above over-all talweg characteristics. Flume research indicates that in a 180-degree bend the bed load is a third less than in a straight channel. In an S channel the load per unit width, for all widths of the experimental flume, is 20 per cent less than in a straight channel of the same length. In straight and curved channels the bed load moves in a band not so wide as the channel. In a bend with increasing discharge this band moves from the pool or deep up the inner bank, and little or no load moves through the deep. In S curves the deeps move upstream with increasing flow. A certain ratio of bend radius to width will yield a continuous stable talweg through an S curve.

EFFECT OF MANGANESE ON THE SPHALERITE GEOTHERMOMETER

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Isothermal sections in the system ZnS-FeS-MnS were investigated at 700°, 800°, 950°, and 1050°C. Attention was paid to the limits of compositional variation of phases showing extensive solid solution. Runs were made in sealed, evacuated, silica-glass capsules in which the pressure was the vapor pressure of the phases present.

In the 3-phase field, sphalerite + pyrrhotite ($FeS_{1.00}$) + vapor, increasing Mn reduces the solubility of Fe in sphalerite. The temperature-composition surface between the 3-phase field sphalerite + pyrrhotite + vapor and the 2-phase field sphalerite + vapor was determined at 700° and 800°C., and points on this surface are given below.

The 4-phase field, sphalerite + wurtzite + pyrrhotite + vapor, intersects the 2-phase field, sphalerite + vapor, along a curve bounding the region sphalerite + pyrrhotite + vapor. This intersection, determined at 700°, 800°, and 894°C., defines the composition of sphalerites in equilibrium with wurtzite, pyrrhotite, and vapor.

Temperature °C	*Mol per cent ZnS*	*Mol per cent FeS*	*Mol per cent MnS*	*Remarks*
800	68.0	32.0	0	
800	68.1	30.9	1.0	
800	68.2	29.8	2.0	
800	68.4	28.6	3.0	
800	69.5	26.5	4.0	Points defining the composition of sphalerites in equilibrium with pyrrhotite and vapor
700	74.2	25.8	0	
700	74.2	24.8	1.0	
700	74.3	23.7	2.0	
700	74.5	22.5	3.0	
700	74.9	21.1	4.0	
700	75.8	19.2	5.0	
894	62.3	37.7	0	Points defining the composition of sphalerites in equilibrium with wurtzite, pyrrhotite, and vapor
800	70.2	25.6	4.2	
700	76.1	18.7	5.2	

SEQUENCES IN THE CRATONIC INTERIOR OF NORTH AMERICA

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The concept of major rock-stratigraphic units of interregional scope was introduced in the Symposium on Sedimentary Facies presented by the Society in 1948. After 10 more years of experience in application it is possible to restate the sequence concept in more intelligible form and to define more explicitly the sequences recognizable in the continental interior of North America.

The sedimentary record of the North American craton from Late Precambrian to present is characterized by six major unconformities which can be traced interregionally. The unconformities serve to subdivide the cratonic stratigraphic column into six sequences—major rock-stratigraphic units (of higher than group or supergroup rank) that can be identified, where preserved, in all cratonic-interior areas. At the cratonic margins the bounding unconformities tend to become lost in continuous successions, and the cratonic sequences are replaced by others controlled by events in the marginal basins and eugeosynclinal borders.

Although the time values of the unconformities vary widely because of differences in degree of nondeposition and amount of erosion the approximate dates of the regressional maxima represented are:

(1) very Late Precambrian, (2) Early Middle Ordovician, (3) Early Middle Devonian, (4) "post-Elvira" Mississippian, (5) Early Middle Jurassic, (6) Late Paleocene. A seventh major regression is now in progress.

PLEISTOCENE OFFSET ALONG THE SAN ANDREAS FAULT SYSTEM OF THE SAN FRANCISCO PENINSULA, CALIFORNIA

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Early and middle Pleistocene offset along the San Andreas fault on the San Francisco Peninsula probably totals at least 12 miles on the basis of displaced elements of an erosion surface. The lack of offset at a marine terrace on opposite sides of the fault, however, and other geomorphic evidence indicate that late Pleistocene offset in this area apparently has been minimal. By contrast, at least 3 miles of right-lateral strike-slip offset along the nearby divergent Pilarcitos fault during late Pleistocene time is suggested by several lines of geomorphic evidence. In addition, geologic evidence suggests intermittent strike-slip displacement on this fault possibly dating back to the early Tertiary. The Pilarcitos fault thus appears to be an important distributary member of the San Andreas fault system. This interpretation is favored by the small amounts of Pleistocene and pre-Pleistocene strike-slip offset along the San Andreas north of San Francisco reported recently by other workers.

The present configuration of the peninsula and its major geomorphic features apparently is the result of successive middle and late Pleistocene juxtaposition of at least three distinct structural blocks by strike-slip displacement along these two faults. The blocks are characterized by dissimilar geomorphic features, geologic structures, and rock types. The wedge-shaped block between the faults probably reached its present position relative to the block northeast of the San Andreas fault by middle Pleistocene time; the block southwest of the Pilarcitos fault apparently did not move into position until after Sangamon time.

SAND DUNES AND SHORE-LINE HISTORY IN THE PROVINCETOWN AREA, CAPE COD, MASSACHUSETTS*

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Dunes in the Provincetown area, Cape Cod, Massachusetts, cover an area of about 10 square miles and have a local relief of up to 100 feet. Two broad divisions are distinguishable:

(1) At the south is a zone of predominantly stabilized dunes in irregular belts discordant to present shore lines and to active dunes at the north. Ponds and bogs lie between them. These dunes are the oldest in the area, appear unrelated to former shore lines, and are interpreted provisionally to have been formed under periglacial conditions, at a lower stand of sea level, in late Wisconsin time.

(2) At the north is a zone of predominantly active dunes, occurring in broadly arcuate belts subparallel to one another and to the Atlantic shore. Dunes within the belts range from elongate sand ridges to chains of upsiloidal dunes, show much variation in details of morphology, and are extensively modified by blowouts. The dune belts are irregularly convergent eastward, and, from south to north, each is truncated at its eastern end by the adjoining belt on the north. The form, size, and pattern of the dune belts are interpreted to have resulted from their upbuilding along successive shore lines on a growing spit, along which dominant progradation was temporarily halted and reversed to retrogradation. These interruptions are attributed to the effects of changes in sea level due to the combined action of isostatic and eustatic processes. The above findings necessitate considerable revision of the geomorphic history of the Provincetown peninsula as outlined by W. M. Davis in 1896.

* Based on studies carried out under Office of Naval Research contract Nonr-2242(00)

CRYSTAL STRUCTURE OF ACTIVATED CALCIUM-CHABAZITE

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From {hk0} intensity data it was found that the cell contents $Ca_{1.94}$ $Al_{3.9}$ $Si_{8.1}$ O_{24} of activated Ca-chabazite have space-group symmetry $R\bar{3}m$ with the following approximate co-ordinates in a cell with a 9.37Å, α 92°01′:

	Multiplicity	*x*	*y*	*z*
Si,Al	12	.328	.096	.866
O_1	6	.280	.000	.720
O_2	6	.500	.124	.876
O_3	6	.235	.235	.880
O_4	6	.255	.000	.000
⅜ Ca_1	2	.169	.169	.169
⅛ Ca_2	1	.000	.000	.000

The 8-membered rings form apertures, between the large cavities in the framework, that are roughly rectangular with edges 3.2 and 4.6Å and diagonals 4.8Å. The observed integrated electron density for the Ca atoms amounts to only about 1 atom per unit cell instead of 2. The remaining atom must either occur statistically in 1 or more 12-fold or 6-fold positions or be in random motion inside the large cavities. The former is still being tested by successive Fo-Fc syntheses (present R-factor is 0.20), but the latter is preferred in view of the low-angle scattering observed by Dr. P. A. Howells of the Linde Company. The Ca_2 atom lies in an octahedrom of O_4 atoms distant 2.4Å. The Ca_1 atom lies displaced from the center of a distorted 6-membered oxygen ring with 3 near neighbors (O_4) at 2.4Å and 3 distant ones (O_3) at 2.9Å. If only the short distances are considered, the Ca atoms are bonded only to O_4 atoms, giving a very unbalanced charge distribution.

MAGNETIC PATTERNS OVER TRIASSIC DIABASE IN PENNSYLVANIA

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An aeromagnetic survey of the Triassic belt in Pennsylvania reveals contrasting magnetic patterns over a number of diabase intrusive rocks characterized by elliptical outcrop patterns. Positive linear magnetic anomalies are associated with diabase masses interpreted to be steeply dipping dikes; low amplitude, nonlinear magnetic patterns are associated with gently dipping diabase sheets. Preliminary results of laboratory investigations of magnetic properties of the igneous rock indicate that diabase of the steep dikes has a high magnetic susceptibility, whereas the diabase of the gently dipping sheets has a low magnetic susceptibility. The known economic iron-ore occurrences, which are believed to be genetically related to the diabase, are also associated with the more steeply dipping diabase dikes.

Linear positive magnetic anomalies are also found over Triassic sandstones and shales at the upper contact of the gently dipping igneous sheets. These anomalies are due to very fine-grained magnetite which is fairly uniformly dispersed in the sediment near the upper contact. The magnetite appears to have resulted from reduction of authigenic hematite during metamorphism of the ferruginous Triassic sedimentary rocks at the upper contact of the diabase sheets. No such magnetite zones are found at the lower contact of the diabase sheets or associated with the steeply dipping dikes. This suggests upward thermal escape and a metamorphic effect on the sediment which increases as the dip of the contact decreases.

CRETACEOUS COAL MEASURES IN UTAH

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Cretaceous coal beds of Utah were formed in swamps generally almost parallel to the strand and separated from it by coastal sand bars; they are commonly extensive along the strike of the littoral but narrow normal to it. Five environments shifted back and forth as land encroached upon sea, and periodic subsidences (or eustatic pulses of sea level) brought the sea back (the vertical successions are of 12341234 type, not 1234321 as would be produced by uniform oscillation). The result is an interwedged body of rock in which the succession of facies can be traced laterally as well as recognized vertically in local stratigraphic sections. Major cycles can be recognized, each distinguished by a prominent coal bed overlying a littoral marine sandstone, and within the cycles are two to four other coal beds; the larger number of beds is usually inland.

The rocks in these major cycles form natural units of the type usually set apart as formations or members, but their narrow extent normal to the strike of the Cretaceous strand and their considerable number pose a problem of nomenclature; available stratigraphic standards do not apply.

These occurrences illustrate a fundamental principle: whatever is found in essentially uninterrupted vertical succession must also potentially exist side by side. Change in vertical succession came as given sediments encroached laterally over those of the neighboring environment. Closely similar sections only a few miles apart belong to different cycles and would be easily miscorrelated were not the rocks nearly perfectly exposed and thus actually traceable.

RELATIONSHIP OF THE SOURCE AND DEPOSITIONAL ENVIRONMENT OF THE TUSCALOOSA GRAVEL IN WESTERN TENNESSEE TO THE PASCOLA ARCH

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Gravel in the Tuscaloosa formation, of Late Creataceous age, occurs as discontinuous remnants resting on Mississippian bedrock in the Western Highland Rim in Tennessee. Main components of the gravel are Mississippian chert, Devonian chert, and sandstone of Devonian, Ordovician, or Cambrian age. The Mississippian chert was derived locally, but the other components must have come from a western source. The source area was the Pascola arch, an eastward-sloping extension of the Ozark dome. At present, the Pascola arch is deeply buried beneath the Mississippi Embayment.

The unsorted, poorly bedded Tuscaloosa gravel is believed to be of terrestrial origin and was deposited on the eastward-sloping flank of the Pascola arch. Elevations at the site of deposition ranged from considerably above sea level to sea level. To the east, the typical nonmarine gravel interfingers with a northward-trending belt of quartz gravel, quartz sand, and clay. These deposits may represent material swept in from north or south by longshore currents. To the west, the Tuscaloosa is overlapped by marine strata of Cretaceous age.

Before and during Tuscaloosa time, the Ozark dome and Cincinnati arch were connected by the Pascola arch. At that time the Pascola arch stood structurally about 3000 feet higher than at present, and its structural shape and dimensions were comparable to those of the Nashville dome. During Tuscaloosa deposition the Nashville dome was structurally about 1000 feet lower than at present, and its crest was probably submerged beneath the sea.

STRATIGRAPHY AND PALEONTOLOGY OF A LATE PLEISTOCENE BASIN, HARPER COUNTY, OKLAHOMA

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Pleistocene (Illinoian) deposits exposed in the Doby Springs area, Harper County, Oklahoma, were deposited in a collapse basin resulting from solution of salt or anhydrite in the underlying Permian strata. The Permian Whitehorse group, the Pliocene Ogallala, and the Pleistocene Crooked Creek formations form the rim of the basin.

In Kansan time a southeastward-flowing stream cut through the Ogallala formation into the Permian strata and deposited the Crooked Creek formation in its valley. A caliche formed in the top of the formation during Yarmouth time. In Illinoian time a collapse basin formed in the Doby Springs area. Lake sediments containing the Doby Springs local fauna were deposited in this basin. Settling and collapse along the southern edge imparted the present dip to the lake beds. In Sangamon time the area was drained, and a caliche formed in the upper part of the lake sediments. Collapse in late Sangamon time produced a north dip in the beds of the northern part of the basin. The alluvial deposits along the modern streams are of Wisconsin and Recent age.

The Doby Springs local fauna contained in the Illinoian lake deposits consists of the remains of ostracods, mollusks, amphibians, reptiles, birds, and mammals. The fishes and mammals indicate a cool, upstream lake environment. The lake was surrounded by marsh, lowland meadow, and some dry uplands. The climate in the area during Illinoian time was probably similar to the climate in the southeastern part of North Dakota today.

LEAD-ISOTOPE AGE STUDIES IN CARBON COUNTY, PENNSYLVANIA

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Lead-isotope age determinations have been made on two samples of uraninite (nos. 346, 538) from the Mt. Pisgah deposit in the basal sandstone and conglomerate member of the Pottsville formation (Pennsylvanian) near Jim Thorpe (formerly Mauch Chunk), Pennsylvania. Two samples of uraninite (403, 586) and a sample of clausthalite (512) have also been studied from a uranium occurrence in the upper part of the Catskill formation (Devonian) near Penn Haven Junction. In addition specimens of galena collected at Nesquehoning from the Allegheny formation? (Pennsylvanian) (584) and from tension fractures in the Portage formation (Devonian) (529) near Walcksville have been analyzed. The data obtained are:

Number	*Per cent Pb*	*Per cent U*	*Atom ratios*		
			Pb^{206}/Pb^{208}	Pb^{207}/Pb^{208}	Pb^{207}/Pb^{206}
346	0.65	14.4	0.029 ± 0.003	$0.0563_7 \pm 0.0003$	$10.5_7 \pm 0.04$
538	0.21	4.34	0.027 ± 0.001	$0.056_0 \pm 0.0001$	$11.1_6 \pm 0.05$
586	3.30	12.4	$0.0260_5 \pm 0.0001$	$0.412_7 \pm 0.0009$	$0.438_7 \pm 0.0002$
403	0.055	0.50	$0.0263_5 \pm 0.0001$	$0.338_8 \pm 0.0003$	$0.451_7 \pm 0.0002$
512	48.6	4.0	$0.0262_7 \pm 0.00002$	$0.783_7 \pm 0.0018$	$0.409_5 \pm 0.0008$
529	83.9	0.0007	$0.0261_6 \pm 0.0003$	$0.846_0 \pm 0.0014$	$0.408_1 \pm 0.0008$
584	79.3	0.003	$0.0260_9 \pm 0.0001$	$0.827_2 \pm 0.0002$	$0.408_0 \pm 0.0005$

Using the galena from Nesquehoning and Pb^{208} as the common lead index the following approximate, discordant "trial ages" in millions of years were obtained:

Number	Pb^{206}/U^{238}	Pb^{207}/U^{235}	Pb^{207}/Pb^{206}
403	243	249	295
586	438	428	375
346	315	324	395
538	296	307	385

An evaluation of these discordant age data, made by using new graphical methods, suggests that both uranium occurrences were emplaced approximately 120 million years ago.

STRONTIUM CONTENT OF CALCITES FROM THE STEINPLATTE REEF COMPLEX, AUSTRIA

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The Triassic Steinplatte Reef complex is well exposed between Lofer and Waidring, Austria. Samples were taken along a section of the reef complex from the backreef to the forereef and basin areas and have been analyzed for strontium by means of an X-ray-fluorescence technique.

Two generations of calcite were distinguished on the basis of petrographic criteria, and these were found to be characterized by appreciably different concentrations of strontium.

In the backreef area the strontium content of calcites was found to range between 60 and 150 ppm. Calcites from the forereef area were found to have a strontium content of 150–420 ppm; the trend toward higher strontium content from the backreef to the forereef area was found to continue into the basin area, where calcites with strontium contents between 380 and 1570 ppm were found.

Mineralogic, petrographic, and structural data prove that most of the reef complex has been thoroughly recrystallized. The strontium content of calcites from the backreef and forereef areas supports this conclusion, since by comparison with unrecrystallized reef material, the strontium content of the Steinplatte is extremely low. The higher strontium content and the preservation of organic structures in materials from the basin area suggest that recrystallization has been much less thorough there. Work now in progress suggests that the solutions responsible for recrystallization within the reef were not sea water.

NEW GRAPHICAL AND ALGEBRAIC METHODS FOR THE EVALUATION OF DISCORDANT LEAD-URANIUM AGES

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Many uranium-bearing samples give discordant lead-isotope ages. This lack of internal agreement among the Pb^{206}/U^{238}, Pb^{207}/U^{235}, and Pb^{207}/Pb^{206} ages has been attributed to uncertainties in the common lead correction, selective loss of radioactive daughter products, loss or gain of lead or uranium, and contamination by older radiogenic lead.

Wetherill developed a graphical procedure for the calculation of discordant lead-uranium ages using a plot of the mole ratios of Pb^{206}/U^{238} versus Pb^{207}/U^{235} corrected for common Pb^{206} and Pb^{207}. Extending his procedure, concordant ages corrected for common lead can be obtained on plots of mole ratios of total Pb^{206}/U^{238} versus total Pb^{207}/U^{235} using only the Pb^{207}/Pb^{206} ratio of the contaminating common lead.

If isotopic age data are available for two samples from the same or equivalent deposits or outcrops whose ages are assumed equal, plots of $\frac{Pb_a^{206}/Pb_a^{208} - Pb_b^{206}/Pb_b^{208}}{U_a^{238}/Pb_a^{208} - U_b^{238}/Pb_b^{208}}$ versus $\frac{Pb_a^{207}/Pb_a^{208} - Pb_b^{207}/Pb_b^{208}}{U_a^{235}/Pb_a^{208} - U_b^{235}/Pb_b^{208}}$ or normalized with Pb^{204} if Th is present can give concordant ages corrected for unknown amounts and ratios of common lead. Data on three related samples will give concordant ages corrected in addition for one unknown period of alteration or the presence of an older radiogenic lead of unknown Pb^{207}/Pb^{206} ratio. Algebraic solutions equivalent to the graphical methods have also been derived.

The validity of these concordant age solutions may be evaluated in terms of the geologic history of the area, geologic age relations of the enclosing rock, probable sources of the lead and uranium, and the isotopic composition of the lead in associated nonradioactive minerals.

RELATIONSHIPS BETWEEN SELECTED MINERALS, TRACE ELEMENTS, AND ORGANIC CONSTITUENTS OF SEVERAL BLACK SHALES

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The relationships between and among the mineral, organic, and trace-element constituents of samples of the Chattanooga and the Ohio shales in the United States, the St. Hippolyte of France, and the Alum shale of Sweden have been investigated and are discussed in terms of the geochemical environments. The relative importance of the environmental factors is evaluated.

A total of 280 samples was analyzed for total carbon, organic carbon, aliphatic and aromatic hydrocarbon, carbonate, total iron, iron oxides, pyrite, total silicates, quartz, kaolinite, illite, amorphous silicates, uranium, molybdenum, manganese, and quartz grain size. The data obtained were analyzed using correlation and factor-analysis statistics.

On the basis of this study, the writer concludes that the compositions of the shales investigated are highly dependent on the geological factors of environment. The redox potential, the nature of the basin of deposition, marine or continental, and the rate of deposition apparently control the mineralogical and chemical composition of black shales. The nature of the organic material, bituminous or carbonaceous, appears to be related to both the type of material available and to the oxidation of the sediment during deposition.

These geological factors are interrelated, and the composition of a shale is the result of the joint action of these factors during deposition.

ISOMORPHOUS SUBSTITUTION AND INFRARED SPECTRA OF CLAYS

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Infrared absorption spectra of several dozen synthetic authenticated dioctahedral and trioctahedral clays in the region between 5000 and 400 cm^{-1} have been obtained. Characteristic changes of IR spectra with isomorphous substitution have been observed with both families.

In many cases a quantitative relationship between frequencies or intensities of the characteristic absorption bands and the amount of isomorphous substitution could be established—*e.g.*, alumina for magnesia or silica for alumina. Thus in the dioctahedral clays (*e.g.*, beidellites) the intensities of two absorption bands at 538 cm^{-1} and 475 cm^{-1} could be correlated with the amount of alumina in the tetrahedral sites. The amount of magnesia in the octahedral sites with montmorillonites or with the members of the muscovite-phengite series could be correlated with the changes in frequency in three absorption regions 870–930 cm^{-1}, 720–830 cm^{-1}, and 520–550 cm^{-1}.

With trioctahedral clays (*e.g.*, saponites) the amount of alumina present in the tetrahedral sites could be quantitatively correlated with the frequency of the absorption band between 650 and 670

cm^{-1}. Infrared spectra of 7 Å and 14 Å chlorites show characteristic changes as a function of the amount of alumina in the crystal lattices of these minerals.

From the obtained results some general conclusions concerning the variations of IR spectra with isomorphous substitution in both groups of clay minerals can be drawn. The results obtained with synthetic specimens have been applied to a few analyzed natural specimens.

MINE SUBSIDENCE IN THE PITTSBURGH DISTRICT, PENNSYLVANIA

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Two hundred years of mining coal in the Pittsburgh area has created geological problems involving land utilization and water supply. Engineering-geology problems are primarily concerned with the subsidence effects of past, present, and future mining as they affect public safety and property damage to buildings, roads, and other structures dependent on ground-surface support.

Analysis of these problems involves considerations of depth of cover over the mine, topography, time of mining, method and extent of mining, structural and stratigraphic relationships, and engineering, architectural, and utilitarian aspects of the design and purpose of the structure.

Successful utilization of undermined land depends on (1) accurate analysis of adequate remaining ground-surface support or adequate stabilization re-established by natural forces, or (2) remedial measures such as balancing of forces by excavation, transmission of construction loads through the mine to firm support below, refilling of mine voids, cementation of fractured roof strata, and grouting of piers in the mine to add the additional increment of support needed below the rock roof of the mine to balance the additional load of the structure to be imposed on the roof.

MISSISSIPPIAN LIMESTONE BOULDER CONGLOMERATES IN THE SOUTHERNMOST SANGRE DE CRISTO MOUNTAINS, NEW MEXICO

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Limestone boulder conglomerate beds of Mississippian age are present over a wide region north of Pecos, New Mexico. These occur through a total thickness of 25–40 feet, but two stratigraphic units of strikingly different origin are represented.

The lower 10–20 feet represent a conglomerate of depositional origin with rounded cobbles and boulders up to 2 feet in diameter in a sandy, calcareous matrix. The boulders include several different types of limestone that vary considerably in composition, and evidence of irregular bedding occurs in a few places. The base of this layer is slightly undulating but distinct and continuous. A possible explanation for such a wide lateral distribution of limestone boulders is erosion of limestone cliffs by an advancing sea, a theory supported by the fact that measurements of boulder dimensions show little lateral change. This conglomerate rests with slight angular unconformity on a thin sequence of even-bedded limestones and dolomites, which rest on the Precambrian or on a thin sandstone of unknown age.

The beds overlying this lower unit consist of 8–20 feet of thick-bedded limestones that pass laterally into and alternate with collapsed structures and channels filled with both brecciated masses and rounded boulders developed from recurring karst topography alternating with marine deposition.

The highest beds of Mississippian age consist of silty, cross-bedded limestones up to 40 feet thick that rest unconformably on the upper boulder unit and are overlain unconformably by lower Pennsylvanian sandstones and shales.

DISTRIBUTION AND STRATIGRAPHIC SIGNIFICANCE OF CONODONTS IN THE TYPE SECTION OF THE CINCINNATIAN SERIES

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Vertical distribution of conodont elements representing some 60 species defines 4 zones in the reference section of the Cincinnatian series in Ohio, Kentucky, and Indiana. The fauna of Zone I, coextensive with the Eden formation, is dominated by long-ranging Midcontinent species but is distinguished by the presence of a few species of typically Anglo-Scandinavian genera. Zone II, in the Fairview formation, contains, in addition to ubiquitous Midcontinent species, a perhaps indigenous group of robust new species of *Cordylodus*, *Eoligonodina*, *Oulodus*, and *Prioniodina*. In addition, *Ambalodus*, *Amorphognathus*, and *Belodina* range into Zone II but not above it. Zone III, in the MacMillan formation, contains a reduced fauna of long-ranging Midcontinent species, whereas Zone IV, in the Richmond group, is distinguished by the virtual absence of long-ranging Midcontinent forms and the appearance of distinctive species of *Aphelognathus*, *Panderodus*, *Rhipidognathus*, and *Zygognathus*, some 60 per cent of which are new to the Cincinnati region. Zone I conodonts occur in the Stewartville and Dubuque formations of Iowa and Minnesota; Zone II conodonts are known from the lower three members of the Iowa Maquoketa, the Orchard Creek shale of Missouri, the Maravillas of Texas, the upper Bighorn of Wyoming, and the Shamattawa of Manitoba. Zone III species are found in the lower Brainerd member of the Iowa Maquoketa; Zone IV forms do not seem to be widely distributed but probably occur in the upper Brainerd member of the Iowa Maquoketa.

STRATIGRAPHY OF THE CUYAHOGA FORMATION AND SHENANGO SANDSTONE OF NORTHERN OHIO AND NORTHWESTERN PENNSYLVANIA

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The Lower Mississippian Cuyahoga formation comprises a maximum of approximately 600 feet of intergrading fossiliferous shelf deposits of siltstone and shale and sparsely fossiliferous nearshore sediments of sandstone and conglomerate. The prevailing north-northwest and north-northeast dips of cross-beds in the coarse-grained Black Hand and Rittman members, and the disappearance by stratigraphic pinchout toward the west of the Sharpsville member in Cuyahoga County, Ohio, and the Rittman beds in Wayne County, Ohio, suggest that most of the clastics were derived from a source area located southeast, east, and perhaps northeast of the region studied.

The Shenango sandstone was traced from the type region in Pennsylvania into Trumbull County, Ohio, where it thins and wedges out. Field evidence suggests that this unit and the overlying Hempfield shale are coeval with the upper part of the Meadville member of the Cuyahoga formation of Medina and Cuyahoga counties, Ohio.

Evidence based on a study of 134 invertebrate fossil species indicates that the Cuyahoga formation is partly Kinderhookian and partly Osagian. The Sharpsville fauna, which includes the ammonoid *Imitoceras discoidale*, is probably Kinderhookian. The overlying Meadville member contains a mixed late Kinderhook-early Osage assemblage; the lower part is probably Kinderhookian, the upper part Osagian. Brachiopods from the uppermost portion of the formation are unequivocal Osagian, probably Burlington forms.

NEWLY DISCOVERED CONCHOSTRACAN-BEARING BEDS OF THE NINNESCAH FORMATION OF KANSAS

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Norton (1939) described 7 scarp-forming beds (limestones or siltstones) of the Ninnescah. Fossil

estheriids were reported in his beds nos. 1, 2, 5, and 7 only. They were said to be absent above his bed no. 7 in Kansas. The present study extends these findings. Above Norton's bed no. 7 and below the Runnymede member of the Ninnescah, 8 fossil estheriid zones were found, thus extending the known vertical range of these forms in Kansas.

Twenty-eight distinct fossil clam-shrimp zones were found in shales and thin argillaceous limestone below Norton's capping beds nos. 1–7 inclusive. For example, fossil estheriids were found above the Milan limestone (top of the Wellington) as follows: 3.0 feet above, in blocky red shale; 6.8 feet above, in waxy light-green shale; 15.0 feet above, in light-green shale; 26.0 feet above, in gray-red argillaceous limestone; 30.9 feet above, in light-green argillaceous limestone. Previously, estheriids were known only from the capping limestone of this unit (Norton's bed no. 1).

Echinestheria-type estheriids were not found above the lower Upper Wellington although they were searched for. This last finding provides the first documentation of the stratigraphic utility of fossil estheriids in the midcontinent Leonardian.

The results reported here and previously make it now possible to initiate a stratigraphically related study of evolutionary changes in fossil clam-shrimp populations from Wellington through Ninnescah time.

AGE OF GRANITIC PLUTONS IN EASTERN OREGON

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Emplacement of granitic intrusive rocks denotes the last major episode of pre-Cenozoic plutonism in eastern Oregon. Batholiths are represented mostly by tonalite and granodiorite, whereas stocks contain mostly tonalite.

The plutons cut country rocks as young as Upper Triassic. Strongly deformed Jurassic (Callovian) strata indicate deformation before or accompanying emplacement of plutons. Cretaceous strata show relatively mild deformation in comparison to Jurassic and Triassic formations.

Marine Cretaceous (Albian) conglomerates in central Oregon contain pebbles of tonalite and granodiorite. Except for degree of weathering, the granitic pebbles are microscopically indistinguishable from specimens from many plutons. Modal analyses (700–900 mm² per thin section) compare closely with analyses of rocks from the batholiths and stocks. Analyses of seven pebbles of tonalite and three pebbles of granodiorite gave an average composition (volume per cent) as follows:

	Tonalite	*Granodiorite*
Quartz	27.9	29.8
Plagioclase	55.5	49.0
Potassium feldspar	1.2	7.6
Biotite	9.8	8.4
Hornblende	4.1	4.1
Accessories	1.5	1.1

Direct and indirect field evidence indicates that the tonalite and granodiorite are post-Callovian and pre-Albian. More precise dating must await radiogenic age determinations.

FAULTING ASSOCIATED WITH THE FUYK VALLEY ANTICLINE, SOUTHEASTERN NEW YORK

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Extensively folded and faulted upper Silurian and lower Devonian strata form the Kalkberg ridge of hills lying east of the Catskill Mountains in southeastern New York. Deformation is most intense

in the southern and central portions of this ridge and decreases northward where, although the folds remain asymmetric and are even slightly overturned in places, the two major longitudinal normal faults in the area have throws of only a few meters. In addition, the southwestward-plunging nose of a structure that is here called the Fuyk Valley anticline, is cut by at least three low-angle thrust faults, each showing a comparatively small heave from the east. Transverse normal faulting in turn cuts the thrust blocks. Relaxation of pressures apparently followed compression.

Variations over comparatively short distances in the nature and intensity of folding and faulting in this area probably reflect the action of local rather than regional forces and may be the result in part at least of gravitational sliding. The folded structures appear to have formed during the Acadian disturbance.

PETROLOGY OF THE NEMEGOSENDA ALKALINE COMPLEX, ONTARIO

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The Nemegosenda alkaline complex, located near Chapleau, Northern Ontario, consists of a central mass of coarse-grained alkaline igneous rocks surrounded by an aureole of metasomatic types derived from gneissic country rock. Important niobium mineralization is associated with the complex.

The outermost metasomatic zones and the fenitic gneiss and alkalic fenite zones retain original gneissic foliation. The fenitic gneiss contains remnants of original gneiss minerals that do not persist in the reddened alkalic fenites. The inner pyroxenitic and syenitic contact zones adjoin the igneous center. The pyroxenitic zone, a concentration of sodic pyroxene, intervenes between the syenitic contact zone and the alkalic fenite. The writer concludes that with increasing metasomatism the components of the alkalic fenite were separated into the iron-rich pyroxenitic zone and the inner, silica-deficient, syenitic contact zone in which pyroxene was unstable.

The pyroxenitic zone is the chief locale for the higher grade niobium mineralization. Pyrochlore is the only niobium-bearing mineral recorded.

The central igneous rocks are considered to represent fenites that became liquefied and capable of differentiation. Basic alkalic dikes and cerium-bearing dolomite dikes are present.

The strong analogies between the Nemegosenda and Alnö Island (Sweden) alkaline complexes indicate that both are of similar origin. The writer suggests that the Nemegosenda complex represents a lower erosional level than Alnö.

TACONIC SEQUENCE IN NORTHERN WASHINGTON COUNTY, NEW YORK

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In the Taconic sequence, two Lower Cambrian formations are recognized. The lower, named the Bull formation, consists of the Bomoseen grit member and an overlying Mettawee slate member; the latter has limestone conglomerates locally bearing the *Elliptocephala asaphoides* fauna and correlated with the type Schodack. The Bull formation includes the Zion Hill quartzite. The overlying Lower Cambrian formation, essentially of black shales incorrectly named Schodack and later renamed Hooker, contains limestone conglomerates bearing the *Elliptocephala asaphoides* fauna and an overlying *Paedeumias* fauna with *Paedeumias* sp., Agnostids, *Bonnia* sp., *Fordaspis nana*, *Calodiscus lobatus*, *Hyolithellus micans*, and brachiopods. Black shales with associated rotten-weathering bluish-gray sandstones, incorrectly named Zion Hill, contain an Upper Cambrian fauna with *Callograptus* sp., *Dendrograptus* sp., and, rarely, *Dictyonema* sp.

The overlying Poultney slates, dominantly white-weathering bluish-gray argillites, contain alternating thin dolomitic sandstones and greenish banded argillites and black shales with thin ribbon

limestones and limestone conglomerates in the lower part. The latter, which has thin interbedded sands and ribbon limestones, is lithologically identical with the type Schaghticoke. The Poultney slate contains Normanskill graptolites in the upper part and passes conformably into the Indian River formation of red and bluish-green glazed slates.

PALEOCURRENT AND SEDIMENTARY STRUCTURE STUDIES IN UPPER PALEOZOIC ROCKS OF CENTRAL IDAHO

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Upper Paleozoic strata in central Idaho contain abundant primary sedimentary features, including cross-stratification, convolutions, slump and flame structures, and flute, groove, and load casts. Turbidity-current features are intimately associated with oscillation ripple marks and organic markings suggesting shallow-water deposition. Directional current features have been statistically analyzed over a 60-mile belt.

During the Mississippian period, graded graywacke and limestone beds were deposited by turbidity currents from the southwest and northeast respectively, in a rapidly subsiding northwest-trending trough. Currents from the southwest spread laterally in the trough, resulting in partial longitudinal filling. The calcarenite beds that are interbedded with the graywacke beds in the trough originated as slumps on the margins of an eastern carbonate bank. Paleocurrent data from 2 zones in the Wood River formation, sampled over a northwest belt 40 miles long, establish a source area to the west.

Convolutions are overturned with and without current truncation or modification. All gradations between cross-stratification and convolutions occur; many convolutions resulted from overturned cross-stratification. Current structures within some convolutions prove that they were formed penecontemporaneously with deposition. Cavitation is a possible agent of truncation where both convolutions and cross-stratification have been truncated in the upper part of graded beds.

Paleocurrent data from Mississippian strata and from the Wood River formation indicate a statistically valid divergence of the convolution and cross-stratification means. The deflection of current-controlled features (cross-stratification) away from slope-controlled features (convolutions) is the result of other current-affecting factors.

UPPER PALEOZOIC STRATIGRAPHY AND PALEOTECTONICS IN CENTRAL AND EASTERN IDAHO

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Recent studies in central and eastern Idaho allow a revision of the Upper Paleozoic stratigraphy and paleotectonics in that area. Three geographic features controlled sedimentation: (1) a western positive area, (2) an eastern carbonate shelf, and, lying between, (3) a rapidly subsiding trough aligned northwest.

The Milligen formation (pre-middle Mississippian) contains radiolarites deposited in a relatively deep basin. The Milligen-Wood River contact, in the position of the western positive area in west-central Idaho, is a major unconformity. This hiatus is represented in the trough by approximately 10,000 feet of graded Mississippian graywacke and limestone beds, constituting a new formation, which is subdivided into four members.

Deposition was continuous in the trough from Milligen through Mississippian into Wood River (Pennsylvanian-Wolfcampian) time. The frequency of graded beds decreases upward, and the clastics change from graywacke to orthoquartzite.

The Wood River formation climbs through time and overlaps the Milligen to the west. It is subdivided into four lithologically distinct, accurately dated members. The Mississippian strata and

Wood River formation change facies abruptly to the east and are equivalent to a thick limestone sequence (more than 7000 feet in the southern Lemhi Range) which is Meramecian through Wolfcampian in age.

The tectonic history consists of three pulses in the western positive area: one minor middle Mississippian pulse, a stronger pulse in Chesterian, and a third strong pulse in lower Pennsylvanian. These orogenic movements coincide in time and are aligned with the Antler orogeny in Nevada, and this term is extended into central Idaho.

CRUSTAL SECTION ACROSS CALIFORNIA AND SIERRA NEVADA

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Two-dimensional computation methods developed by Talwani, Worzel, and Landisman (1959) made possible the interpretation of gravity data extending from the Pacific Basin across the edge of the continent, the Coast Ranges, the Great Valley of California, the Sierra Nevada, and part of the Basin and Range Province. Superimposed upon two major changes in the level of the Bouguer anomaly associated with the edge of the continent and the western margin of Sierra Nevada are anomalies caused by the largest masses in the upper part of the crust: (1) a negative anomaly caused by sedimentary rocks of the Great Valley, (2) a positive anomaly associated with the "greenstone belt" in the western Sierra Nevada, (3) negative anomalies due to the granitic batholiths in the Sierran region, and (4) a negative anomaly explained by postulating thick sedimentary rocks on the continental slope and rise. After analysis and allowance for these masses, the undulations of the lower boundary of the crust were computed. The results indicate a thickening of the crust from about 15 km (including the water layer) in the Pacific Basin to about 50 km in the western part of the Basin and Range Province. Locally the crust thickens in the Coast Ranges and thins in the Great Valley. The depth of the "root" in the Sierran region depends on the inferred size of the granitic batholiths. Conventional isostatic anomalies along the entire section are related more to inhomogeneities of mass in the crust than to departures from buoyant equilibrium.

NATURAL VARIATIONS IN ISOTOPIC-ABUNDANCE RATIOS OF SILICON

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High-precision mass-spectrometric techniques, using dual ion-beam collection and twin gas sample systems, have been applied to measure small naturally occurring variations in isotopic abundances of silicon. Using high-yield wet chemistry, silicon is removed from minerals with flux and converted to $BaSiF_6$ which is then decomposed by heating to give SiF_4 gas for admission to the mass spectrometer. The total range of all observations to date on natural samples is about 5 per mil, and typical precision is between 0.1 and 0.2 per mil.

Measurements have been made on meteorites and ultrabasic rocks, all of which have similar ratios, and all of which are lighter isotopically than the average whole-rock values for the more highly silicic rocks. Measurements have also been made on tektites.

Maximum emphasis has been on studying differences between coexisting minerals in igneous rocks and in pegmatites. Measurements have been made of the silicon isotopic ratios in quartz, biotite, and feldspars from several rocks of the Yosemite region and from some pegmatites. Some of the rocks studied, both pegmatitic and fine-grained, display total spreads of 2 to 3 per mil among the major minerals, whereas other rocks that are grossly similar show differences an order of magnitude smaller for the same minerals.

Speculations concerning the processes responsible for the differences found, the implications for

geothermometry, and possible applications to other studies of environments and conditions of formation of granites and pegmatites are discussed.

COMPOSITION OF FELDSPARS AND CRYSTALLIZATION HISTORY OF THE GRANITE-SYENITE COMPLEX NEAR SALEM, ESSEX COUNTY, MASSACHUSETTS

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Compositions of $CaAl_2Si_2O_8$-poor microperthites from granites and syenites in the area near Salem, Massachusetts, determined by an X-ray-diffraction method on thermally homogenized material and by chemical analysis, are interpreted in light of recent experimental work in the system $KAlSi_3O_8$—$NaAlSi_3O_8$—SiO_2—H_2O to yield information on the crystallization history of the rocks. Massive syenite, syenitic dikes, and porphyritic microgranite are marginal to the large area of microperthite granite that extends eastward from Salem to Rockport, Massachusetts. Microperthite phenocrysts of the porphyritic microgranite (Or_{56-61}, weight per cent) are more potassic than feldspars of the granite (Or_{44-52}), in agreement with experimental crystallization paths and the interpretation of the porphyritic microgranite as a chilled border zone of the granite. Field evidence shows that the syenite represents one or more showers of feldspar crystals probably resulting from volcanic devolatilization of the granitic magma. Where the pluton had a gently dipping floor the feldspars accumulated to form syenite. The compositions of the syenite feldspars (Or_{24-43}) reflect a shift in liquid-crystal equilibria such that the liquid, after devolatilization, crystallized feldspars more sodic than itself. This also agrees with the experimental work. Feldspars of syenite dikes (Or_{27-31}) coincide with the minimum in the system $KAlSi_3O_8$—$NaAlSi_3O_8$—H_2O, suggesting an origin by remelting of massive syenite.

RELATION OF THE TODILTO LIMESTONE URANIUM DEPOSITS TO COLORADO PLATEAU URANIUM DEPOSITS IN SANDSTONE

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Because the uranium deposits in the Todilto limestone near Grants, New Mexico, are different lithologically, they have also been considered different genetically from the uranium deposits in sandstone of the Colorado Plateau.

Characteristics of the deposits in sandstone are: (1) The chemistry and mineralogy are simple. Uranium is usually associated with vanadium, and few other elements are present. The primary ore contains uraninite, vanadium oxides, and coffinite and oxidizes chiefly to uranyl vanadates. (2) Deposition was epigenetic from circulating waters, controlled by primary sedimentary structures and organic matter, and usually limited to a single formation over a wide area. (3) The consistent association of the deposits with tuffaceous (or arkosic) sedimentary rocks suggests a mechanism of formation involving leaching of uranium from the tuff (or arkose) by carbonate ground water with formation of uranyl tricarbonate complex, which then moves to a different chemical environment where the uranium precipitates.

Deposits in the Todilto, like the sandstone ores, have uraninite, coffinite, and the vanadium oxides haggite and paramontroseite, which oxidize to uranyl vanadates and silicates. They occur over a large area in the Todilto within intraformational structures. They are associated with organic matter which is intimatey incorporated into the limestone to give a fetid odor and also occurs as minute black glassy masses. The acid insoluble fraction, 4–45 per cent of the unmineralized limestone, contains arkosic and possibly tuffaceous material. Thus uranium deposits in the Todilto limestone are

considered basically similar to the Colorado Plateau sandstone uranium deposits in mineralogy, occurrence, and origin.

FACTORS CONTROLLING THE TRACE-ELEMENT CONCENTRATIONS IN RECENT AND FOSSIL MOLLUSCAN SHELLS

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In the attempt to apply trace-element and mineralogic criteria in deciphering ancient marine environments, information has been obtained on the factors controlling the trace-element composition of recent molluscan shells and the subsequent effects of burial in a variety of matrices from ancient "well-preserved" shells.

From the results on 100 recent molluscan shells analyzed for aragonite-calcite ratio and magnesium, strontium, and barium it seems that the most important control of the trace-element concentration of a molluscan shell is the generic association rather than any simple parameter such as temperature, salinity, or aragonite-calcite ratio. On the average, clams are higher in strontium and barium and lower in magnesium than snails. The "fractionation factors" of the trace elements in the shells relative to sea water, when compared to calcium, are 0.00041 for magnesium, 0.18 for strontium, and 1.6 for barium. The concentration of other trace elements in molluscan shells is discussed in this light.

During burial the composition of a "well-preserved" shell (*i.e.*, one retaining its luster and original mineralogy) may be altered considerably in some matrices. Barium may be notably enriched in the fossils, and strontium appears to undergo the least change.

The significance of these results in the problems of the mechanism of shell growth, geochemical paleoecology, and replacement is discussed.

STABILITY RANGE OF IRON CHLORITE

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The stability range of daphnite, $5FeO \cdot Al_2O_3 \cdot 3SiO_2 \cdot 4H_2O$, the iron analogue of clinochlore, has been determined at a constant vapor pressure of 2000 bars and 4000 bars ($\approx P_{H_2O} + P_{H_2}$), in terms of temperature and partial pressure of oxygen (P_{O_2}). Daphnite participates in the following reactions, listed in order of decreasing P_{O_2}:

(1) daphnite = hematite + quartz + mullite + vapor
(2) daphnite = magnetite + quartz + mullite + vapor
(3) daphnite = magnetite + quartz + Fe-cordierite + vapor
(4) daphnite = fayalite + magnetite + Fe-cordierite + vapor
(5) daphnite = fayalite + hercynite + Fe-cordierite + vapor
(6) daphnite = fayalite + mullite + hercynite + vapor.

Some of these reactions may be metastable. In most experiments the chlorite involved is the 7 Å polymorph, which is metastable at high temperatures and high pressures; it has been transformed to the 14 Å polymorph repeatedly. Almandine may replace Fe-cordierite at higher pressures, but it was not encountered in this study. Also, mullite may be replaced by another aluminosilicate.

Data for reactions (1) to (5):

Reaction	P_{O_2}	Temperature (°C.)	
		2000 bars	4000 bars
(1)	> Hematite + magnetite buffer	up to 535° ± 10°	580° ± 20°
(2)	Hematite + magnetite buffer to ≈NiO + Ni buffer	535° ± 10° to 575° ± 25°	
(3)	≈NiO + Ni buffer to ≈Magnetite + quartz + fayalite buffer	575° ± 25° to 622° ± 15°	
(4)	≈Magnetite + quartz + fayalite buffer	622° ± 15°	
(5)	≈Magnetite + quartz + fayalite buffer to ≈ fayalite + iron + quartz buffer	622° ± 15° to 622° ± 25°	675° ± 20°

The effect of complete substitution of ferrous iron for Mg is to lower the stability limit by at least 90° (at 2000 bars P_{total}), which is the difference between reaction (5) and Yoder's clinochlore curve. Reactions (1), (2), (3), and (4), which involve oxidation, may lower the stability limit another 87° (to the point at 535°).

DOPPLERITE FROM CRETACEOUS ROCKS IN WYOMING

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A native humic-acid derivative similar to dopplerite occurs in the Mesaverde formation of Late Cretaceous age in Fremont County, Wyoming. The natural jellylike substance dries on exposure to air to a black brittle solid that is soluble in water or alkaline solutions. After solution and removal of insoluble detritus, the dried dopplerite contained: moisture 12.7 per cent, volatile matter 38.6, fixed carbon 21.1, and ash 27.6. The major elements present on a moisture- and ash-free basis were: hydrogen 3.6 per cent, carbon 62.2, nitrogen 2.2, oxygen 29.3, and sulfur 2.7. Spectrochemical analysis of the purified dopplerite indicates the following elements present: sodium, magnesium, calcium, aluminum, iron, and silicon. This suggests that in its natural state the substance is an alkali humate. Infrared analysis of the soluble fraction yields a curve with a very sharp hydroxyl peak, strong unsaturated carbon-carbon (probably aromatic) bonds, and no carbonyl; this is similar to extracts from lignite and subbituminous coal.

The insoluble residue contains particles of cuticle preserved as fusain, spores, pollen, brown resinous fragments, and fine-grained clay, quartz, and mica. Most of the cuticle is probably derived from dense fibrous angiospermous wood. Fungi, moss, fern, and angiosperm spores and pollen are present. Dicotyledonous types identified are consistent with a Late Cretaceous age.

Dopplerite was probably not preserved in a jellylike condition from Cretaceous to Recent time. The fusainized cuticles suggest an origin from consolidated coal. Therefore, the dopplerite is probably a Recent weathering product of Cretaceous coal.

BLACK ROCK SUMMIT BASALT FLOW, NEVADA

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A basalt flow on the west slope of the Pancake Range, near Black Rock Summit, Nye County, Nevada, is the youngest unit in an upper Cenozoic volcanic field composed mainly of cinder cones

and ash deposits. The flow is black and vesicular to scoriaceous. The texture of the nonscoriaceous phase is seriate porphyritic. Phenocrysts of olivine, pyroxene, and plagioclase are as much as 2½ inches long and make up 20–30 per cent of the flow.

On the basis of chemical and X-ray analyses and optical data, the olivine contains 87.0 per cent forsterite molecule, the pyroxene is diopsidic augite, and the plagioclase is An_{66} with K_2O/Na_2O ratio greater than 1/6. The basalt matrix contains 44.8 per cent SiO_2.

The physical appearance of the flow suggests that it crystallized from a lava melt that erupted just as it had begun to differentiate. The composition of this melt may very nearly represent the parent magma for this flow and others in the vicinity. This also applies to the youngest basic volcanic rocks in the nearby Tonopah-Paradise Peak area. The lavas from which the latter rocks crystallized were probably differentiates of a magma whose composition is close to that from which the Black Rock Summit basalt crystallized.

PRESSURE-TEMPERATURE STABILITY CONDITIONS OF SOME REACTIONS IN THE SYSTEM LIME-MAGNESIA-SILICA-CO_2

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The univariant P-T stability curve for the reaction:
(1) calcite + forsterite $\rightleftarrows$ monticellite + periclase + CO_2 has been experimentally determined as a function of P_{CO_2} and T. It passes through the points 800°C. at 2500 psi, 850°C. at 4700 psi, and 900°C. at 7700 psi.

The P-T stability curve for the reaction:
(2) 3 monticellite + diopside $\rightleftarrows$ 2 akermanite + forsterite has been determined and passes through the points 864°C. at 1000 psi and 872°C. at 3000 psi. At 886°C. and 6000 psi, this curve intersects, at a quaternary invariant point, the curves for the reactions:
(3) 2 calcite + diopside + forsterite $\rightleftarrows$ 3 monticellite + CO_2
(4) calcite + diopside $\rightleftarrows$ akermanite + CO_2
(5) akermanite + calcite + forsterite $\rightleftarrows$ 3 monticellite + CO_2.

These data are submitted as additional elements of the petrogenetic grid proposed by Bowen.

HIGH-TEMPERATURE PORTION OF THE THREE-PHASE SOLID-LIQUID-VAPOR EQUILIBRIUM CURVE OF THE SYSTEM NaCl-H_2O

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The pressure-temperature-composition relations in hydrous systems involving water-soluble compounds in which the solid-liquid-vapor univariant PT curve does not intersect the critical curve are of interest in connection with ore-forming solutions and hydrothermal activity in general; yet few, if any, systems of this type have been studied up to the melting temperatures of the compounds. Typical of such systems is NaCl—H_2O. The experimental data reported complete the determination of the S-L-V curve for the system NaCl—H_2O, heretofore studied only at temperatures below 660°C.

Determination of the three-phase S-L-V univariant PT curve in the system NaCl—H_2O shows that the pressure along the curve increases rapidly with a corresponding decrease in temperature. The S-L-V univariant PT curve passes through the following points: 157 atmospheres at 765°C. at which point vapor containing approximately 4 mole % NaCl, liquid containing 70 mole % NaCl, and solid NaCl are in equilibrium; 300 atmospheres at 675°C. where vapor containing approximately

5 mole % NaCl, liquid containing 65 mole % NaCl, and solid NaCl are in equilibrium; 380 atmospheres at 652°C. where vapor containing approximately 6 mole % NaCl and liquid containing 50 mole % NaCl are in equilibrium with solid NaCl.

MOBILITY OF GRANITE IN RELATION TO METAMORPHIC FACIES: I. THE KALLADAR CONGLOMERATE, ONTARIO, CANADA

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Metamorphosed conglomerates containing granite pebbles present unique opportunities to study how granite behaves during metamorphism without ambiguities concerning origin of the granite. A conglomerate in the Hastings series near Kalladar, Ontario, contains abundant granite pebbles in a dark matrix, metamorphosed in the staurolite-quartz subfacies of the almandine amphibolite facies, characterized by the assemblage hornblende-plagioclase-epidote. The pebbles are deformed into elongated, flattened oval discs by paratectonic recrystallization without cataclasis. They show distinct compositional zoning produced by differential migration of chemical components. SiO_2 was extracted and concentrated in a zone of dilatant strain at the rims of the discs, forming quartz "tails" extending tens of centimeters beyond the ends of pebbles as seen in section. Potassium feldspar was removed from an intermediate zone and concentrated in the zone of compression along the flattened sides of the pebbles, producing a border enriched in biotite and tourmaline in the matrix and microcline-enriched patches on the margins of pebbles. Plagioclase is about An_{30} throughout pebbles and matrix, which indicates only adjustment to the facies. Chemical and modal analyses are given of different parts of pebbles and matrix. Petrofabric analysis shows insignificant preferred orientation of quartz in cores of pebbles and distinct orientation in tails. Although granite is chemically mobile in this facies, the components do not move as granite but have different rates and activity gradients. Preliminary studies in lower and higher facies suggest that activity gradients and rates of diffusion of granite components tend to converge in the hornblende granulite facies.

CLASSIFICATION OF PALEOZOIC COAL MEASURES

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Practice in stratigraphic classification of Paleozoic Coal Measures has been greatly varied. The entire coal-bearing sequence is considered a single formation or group in Rhode Island, Alabama, Michigan, Iowa, and South Africa. Productive Coal Measures are separated from Barren Measures in Pennsylvania, Maryland, West Virginia, Ohio, New South Wales, and Tasmania. Gross lithologic types such as quartz-pebble conglomerate separate nonconglomeratic series in West Virginia, Virginia, eastern Kentucky, and Georgia. A single bed has been used as a structural datum to divide thick coal-bearing sequences in Virginia. Cyclic sedimentation with one widespread coal bed per cycle has been used in Illinois and proposed in Ohio, Missouri, and Kansas. More or less widespread key beds have been used to bracket the Coal Measures into a series of formations or groups in Indiana, Ohio, western Kentucky, and a newly proposed classification in Illinois. Fossil zones, especially of nonmarine pelecypods, have been fairly widely used in Coal Measures subdivision in England and western Europe.

Reasons for this diversity in practice are the lithologic heterogeneity of the strata and the fact that the key beds that are useful and prominent in one area thin, disappear, or grade into other sediment types when traced away from a type section. In most coal basins the current classification system seems unsatisfactory. Illinois, Tennessee, and Missouri have developed new or modified systems within the past few years.

SULFUR-ISOTOPE INVESTIGATION OF THE GOLD-QUARTZ DEPOSITS OF THE YELLOWKNIFE REGION*

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Sulfides in the ore bodies and their associated alteration halos, the metamorphic facies of the greenstone belt, and the neighboring granite have been examined in detail. Most samples investigated are slightly enriched in S^{34} with respect to the meteoritic standard. Although the over-all range is small (about 1.5 per cent), variations were found between the granite and the metamorphic facies of the greenstone belt. A direct correlation exists between the isotopic ratio and the distance from the granite contact; sulfides in the granite are the most enriched in S^{34}, whereas the metamorphic facies are progressively depleted in S^{34} as the distance from the granite increases.

Sulfides in early tension fractures are consistently lighter (*i.e.*, they contain more S^{32}) than the sulfides in the surrounding greenstones, whereas sulfides in the later gold-quartz lenses are heavier than those in their associated alteration zones. In addition, profiles across the country rock, alteration zones, and gold-quartz lenses indicate that the heavy isotope has been preferentially retained in the alteration zones with the maximum enrichment in the ore. However, in late crosscutting quartz-carbonate lenses the lighter sulfur isotope has been preferentially concentrated.

The isotopic studies indicate that the primary isotopic distribution of the district was modified by metamorphism during which the S^{32} was mobilized to a greater extent, leaving the sulfides in the hotter regions enriched in S^{34}. The formation of the gold-quartz lenses was associated with intense chemical activity, and the S^{32} was again preferentially mobilized, resulting in a progressive enrichment of S^{34} in the alteration zones and ore.

PETROGRAPHY OF SOME ERRATICS FROM EAST ANTARCTICA

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Thirty-one subangular to subrounded specimens were collected from a terminal moraine of Taylor Glacier (Lat. 77°40′ S., Long. 163°10′ E.) 3–4 miles from the Ross ice shelf. Thin sections of all specimens give the following distribution of rock types: (1) Undoubted metasedimentary rocks, 3 specimens: 2 pure coarse-grained white marbles and 1 metaquartzite. (2) Granites, granite gneisses, and metamorphosed mafic rocks of uncertain origin, 20 specimens. The granitic rocks, except pegmatite and aplite, display extreme hydrothermal alteration and/or dynamic metamorphism. The mafic rocks have granoblastic texture and mineral assemblages typical of the hornblende amphibolite or granulite metamorphic facies. (3) Basic intrusives, 8 specimens. These are medium- to coarse-grained, with ophitic texture and some flow structure, and range in composition from diabase to quartz diorite.

No unmetamorphosed or slightly metamorphosed sedimentary or volcanic rocks are present.

The first two groups probably represent the East Antarctica metamorphic complex. Specimens of the third group are probably differentiates of the thick Cretaceous (?) diabase sills that have been described from this region.

GROUND WATER FROM SPRINGS IN CALHOUN COUNTY, ALABAMA

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A study of 146 springs in Calhoun County was made during 1956–1959 as a part of the groundwater investigation by the U. S. Geological Survey in co-operation with the Calhoun County Board

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of Commissioners and the Geological Survey of Alabama. The purpose of this investigation is to relate the geology of Calhoun County to the occurrence, quantity, quality, and availability of ground water.

The stratigraphy and structural relationships of the rocks in the area are typical of the Ridge and Valley physiographic province. Consolidated rocks ranging in age from Precambrian to Pennsylvanian have been sharply folded into northeastward-trending synclines and anticlines complicated by thrust faults. These thrust faults are the predominant structural feature of the area.

In comparison with springs studied in other parts of the Paleozoic area of northern Alabama, those in Calhoun County have smaller seasonal fluctuations in discharge. A detailed study of the discharges from 10 selected springs was made to determine seasonal fluctuations. Average flows from springs originating along fault zones ranged from 1.4 to 2.3 times the minimum flow; those from aquifers recharged locally were 3.4–6.3 times the minimum flow. The total minimum discharge from springs in the county exceeds 90 million gallons per day.

The fluoride content of water from 14 springs sampled ranged from 0.1 to 0.2 part per million, whereas only 1 of 11 water samples collected from selected wells contained a measurable quantity of fluoride.

MEASUREMENT OF DISSOCIATION PRESSURES IN HYDROUS MINERALS BY THERMISTORS

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A new method has been developed to measure dissociation pressures of hydrous minerals. A thermistor mounted in a heated pyrex cell was used as one arm of a wheatstone bridge to measure the pressure as a function of resistance. Distilled water and mixtures of sulfuric acid and distilled water were used for calibration curves. The vapor pressure of water over gypsum ranged from 150 mm Hg to 760 mm Hg between temperatures of 70° and 100°C. An accuracy of 3–10 per cent was obtained by comparing these values to the manometer method of K. K. Kelley.

The dissociation pressure for the reaction $Al(OH)_3 \rightleftharpoons AlO(OH) + H_2O_{(v)}$ was measured on starting materials whose surface area was 1550–50,000 sq cm/gm. Equilibrium is attained much faster using the material with the high surface area, but the dissociation pressure curve is not essentially displaced. The attainment of equilibrium probably depends on breaking the Al—OH bond in the crystal lattice as well as those on the surface. The reaction that forms water is probably $OH + OH \rightarrow H_2O + O$.

These results suggest that gibbsite should be the stable phase in tropical weathering suites under conditions of high relative humidity, such as tropical rain forests. Boehmite has a stability range under conditions of lower relative humidity.

This technique offers simplicity as compared to manometer and adsorption methods of measuring vapor pressures. It could be applied to evaluate other hydrate systems, such as the borates, at surface temperature and pressure.

DEPOSITION OF URANIUM AT PALANGANA SALT DOME, DUVAL COUNTY, TEXAS

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One of the most unusual uranium deposits discovered in recent years is in shallow sediments above the cap rock of Palangana salt dome in Duval County in south Texas. The basal sand and conglomerate of the Goliad sand (Pliocene) at a depth of about 320 feet is the ore-bearing zone. It is medium- to coarse-grained sand containing clay balls, chert pebbles, chalcedony nodules, disseminated

pyrite, a little petroleum, and a few fossil teeth and coalified wood fragments. A comparison of drill core on the dome with that off the dome shows no significant difference in the Goliad sediments above the ore zone. They are fine-grained sands and silty clays that have calcareous concretions and spots of manganese oxide and are light pinkish gray, orange, or light brown. However, the ore zone and the sediments under it on the dome are greenish gray and contain disseminated pyrite, which is the result of the reducing environment of H_2S emanating from the cap rock. The uranium seems to be chiefly disseminated sooty pitchblende with a small amount of microcrystalline uraninite.

The writers postulate that the uranium was leached by alkaline ground water from abundant tuffaceous material and volcanic pebbles in the Miocene and Pliocene formations northwest of Palangana and that it was precipitated from uranyl carbonate solution in the reducing environment above the salt dome. This hypothesis is supported by the following: extensive development of caliche, highly mineralized ground water, alteration of the tuffaceous material, formation of opal and chalcedony, and many small uranium prospects on the surface.

ISOTOPE GEOLOGY OF THE STEAMBOAT SPRINGS AREA, NEVADA

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Deuterium/H, Tritium/H, O^{18}/O^{16}, and C^{13}/C^{12} ratios of thermal and surface waters, with geological and chemical evidence, greatly clarify the complicated hydrologic relations of the Steamboat Springs volcanic hot-springs area. The major streams have characteristic differences in deuterium, O^{18} and C^{13}, depending on details of origin, evaporational history, and probable influence of organic carbon from soils.

All thermal waters studied, from volcanic areas of abnormally high heat flow in North America, Iceland, and New Zealand, are closely related isotopically to meteoric waters of each particular area, and these meteoric waters generally differ significantly. Qualitatively this proves that each thermal water is dominantly meteoric.

Steamboat Springs water is probably from the Carson Range west of the springs. Steamboat Creek, draining from Washoe Lake to the south, and streams from Virginia Range to the east are improbable sources of recharge. The O^{18}/O^{16} of thermal water is increased by exchange with "heavy" oxygen of silicates and is probably related to hydrothermal alteration. Most meteoric water is more than 30 years old, but thermonuclear tritium contamination proves existence of minor local recharge, with travel times of several months. Water of volcanic origin probably constitutes less than 5 per cent and perhaps less than 1 per cent of the total.

Connate, and probably magmatic and metamorphic, waters differ isotopically and chemically from ordinary surface waters. Studies of waters and solid phases may make possible interpretation of physical environments of epithermal ore deposits and determination of relative influences of waters of different origins.

SYNTHETIC CHALCEDONY

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Synthetic chalcedony, probably first made by Nacken (1948), has anomalous properties that correspond in general to those of natural chalcedony. Low refractive indices (1.48–1.54), distinctive optic properties, characteristic, microscopic as fibrous and banded textures, and quartz structure as shown by X-ray powder patterns, show that the synthetic material corresponds to the natural variety.

The chalcedony was made by transformation of solid materials, chiefly silica glass, in the presence of hydrothermal solutions in runs of 48 hours at moderate temperature and pressure (400°C., 340 atm.). Chalcedony was not directly precipitated from solution but formed only by transformation in

place of silica glass or cristobalite. However, whether transformation took place was determined by the nature of the solution, in particular its alkalinity. In general, no conversion took place in slightly acid solutions, while complete, rapid conversion occurred in slightly alkaline solutions. The peculiar properties differentiating chalcedony and chalcedonic quartz from ordinary quartz are a result of special conditions of nucleation and growth in solid material (silica glass, opal, silica gel, or cristobalite). Also, the conversion proceeds by a series of steps: glass → cristobalite → keatite → chalcedony → quartz. The experimental evidence, which agrees with many observational data on natural material, supports the concept that chalcedony and chert do not form as a direct precipitate from solution but by conversion of solid silica.

DATA DENSITY NECESSARY FOR QUANTITATIVE MODAL ANALYSIS OF A GRANITIC COMPLEX

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A realistic picture of the mineralogical composition and variation of granitic plutons is obtained only by extensive sampling. The following two main aspects of variability investigated in the "older granite" of Donegal, Eire, suggest that each requires a different sampling design for optimum results:

Regional variation: Nonorthogonal polynomial analysis enables partial trend surfaces to be computed for individual mapped variables derived from granite modal data. Analogous surfaces are obtained for each variable by using either one specimen per quarter square mile or the averages of these same specimens within each square mile. The latter surfaces are preferred because they account for a greater proportion of the sum of squares for each variable and involve less labor and IBM 650 time. When only one specimen per square mile is used results appear unsatisfactory.

Deviations from regional variation: The deviations equal observed modal values minus computed surface values for the same location; deviations from partial trend surfaces have geological significance. In the "older granite" deviations can be correlated with xenolithic relics of the structure of pregranite metasediments. In this case deviations based on averages of four specimens per square mile reflect only the generalized structure of pre-existing metasediments, whereas with specimens on a quarter-square-mild grid detailed correlation with the known ghost stratigraphy is possible. Similar conformable deviation patterns occur in "older granite" areas lacking xenoliths and yield the only clue to metasediments present before formation of the homogeneous granite.

These conclusions apply to both major and accessory minerals.

JOINTING WITH RELATION TO GROUND-WATER MOVEMENT IN THE TRIASSIC ROCKS OF NEW JERSEY

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The New Jersey Geological Survey is successfully utilizing the topographic expression of joint systems as a means of locating wells in Triassic sandstones and shales.

A statistical tabulation of well depths and yields in an area is checked against the structure, rock type, and joint systems. Such tabulations are providing clues to the minor changes in rock types, the abundance of argillite, and structure in the areas studied.

A number of case histories and examples are given to show that: (1) movement of ground water through joints within about 200 feet of the surface is relatively free and rapid; (2) at depth there is more rapid ground-water movement in zones of closely spaced joints; (3) not all joint systems are open enough for ground-water movement; (4) the intersection of bedding planes and selected joint systems may provide better openings for ground-water movement than joints alone; (5) at depth, ground-water movement may be at a rate of a few feet per day, with a consequent drop in the

well yield; (6) rapid depletion of wells along a major joint at a distance of half a mile or more may occur while at the same time other wells within 200 yards of the pumping well are unaffected.

PRE-PLEISTOCENE TOPOGRAPHY OF THE HACKENSACK MEADOWS, NEW JERSEY

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Analysis of borings data from the Hackensack Meadows of New Jersey shows that two pre-Pleistocene river valleys are cut more than 100 feet below present sea level in the Triassic sandstone bedrock. The westerly bedrock valley underlies Newark at elevation minus 200 feet and extends northward up the Hackensack River valley to Sparkill Gap, New York, at elevation minus 55 feet.

The easterly valley underlies the eastern meadow margin and follows the valley of Overpeck Creek north to Closter, New Jersey. Since bedrock rises rapidly south of Bayonne and Elizabeth, there is no logical outlet southward. However, a narrow gap through the Palisades at Bayonne shows no rock at minus 150 feet. This suggests that in late Pliocene or early Pleistocene times the Hudson flowed west through Sparkill Gap then south in the present Hackensack Valley until it escaped eastward at Bayonne.

Sand and gravel, interbedded with lake clays opposite many tributary valleys at about elevation minus 50, suggest two periods of glacial lakes with renewed erosion between.

The location of the easterly valley suggests that the dip of the Palisades sill steepens markedly at about the line of the present east border of the meadows.

PROGRESS REPORT ON THE GEOLOGY OF THE SPRUCE RUN DAM AND RESERVOIR, CLINTON, NEW JERSEY

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The topographic basin at the downstream end of Spruce Run near Clinton, New Jersey, was selected for a 10-billion-gallon water-storage reservoir. Folded and faulted Ordovician limestone underlies the dam site and much of the reservoir.

Geologic interpretations based on regional geology, verified and checked by detailed field work, aerial photos, and many cross sections, show the following:

(1) The Ordovician limestone and shale outcrop is not an indropped block, as usually assumed, but is a fenster exposed by erosion of the overlying Triassic fanglomerate.

(2) A pre-Triassic (?) rotational movement crushed an easterly limestone block against the Precambrian crystalline rocks. A westerly limestone block backed by Ordovician shales sustained comparatively little deformation.

(3) The present surface of exposed Ordovician limestone and shale is nearly coincident with a pre-Triassic erosional surface of much greater relief than that in the area at present.

(4) Solution openings developed during pre-Triassic and Recent erosion cycles along joints, faults, and bedding planes. Silts in the earlier openings were cemented by calcite, compacted, and crushed.

(5) Static water levels, active sink holes, and core borings indicate very free ground-water movement in selected structural blocks.

(6) Correct identification of stratigraphic position in the limestone is difficult because of repetition and omission of beds by bedding-plane and strike faults.

(7) An early Pleistocene glaciation filled a part of Spruce Run, possibly changing the drainage system of the stream within the reservoir.

The importance of the application of all phases of geology to engineering problems is illustrated by the project.

USE OF PORE CONCENTRATION IN THE TESTS OF PLANKTONIC FORAMINIFERA FOR CORRELATION OF QUATERNARY DEEP-SEA SEDIMENTS

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In a study of planktonic Foraminifera sampled from certain of Lamont Geological Observatory's Atlantic and Caribbean cores, it was observed that the concentration of pores per unit area of the test walls of certain common species varied through a time interval consisting of early to late Pleistocene and Recent. A simple method of preparing specimens and counting pore concentrations was devised and applied to a particular species, *Globigerina eggeri*. The results show that variations in the pore concentration of this species are seemingly related to the climatic fluctuations of the Quaternary; the smaller number of pores is associated with the colder periods. Variations of pore concentration, plotted as a curve for each core, show a high degree of correlation with curves based on over-all faunal changes and O^{18} determinations on the same core.

Although the exact function of pores in the test walls of planktonic Foraminifera is not known, the possibility that buoyancy or respiration might be involved leads to tentative explanations of the relation of pores to climatic conditions. Whatever the correct explanation may be, variations of pore concentration promise to be a worthwhile supplementary method of correlating Quaternary deep-sea sediments.

METADIORITE FROM NORTHWESTERN MAINE

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The diorite stock occupies an area of 30 square miles immediately north and northwest of Rangeley, Maine, in the Kennebago Lake quadrangle. Adjacent metasedimentary rocks of probable Silurian age (Clintonian in part) include complexly deformed cyclical schists, gray slates and phyllites, and minor intercalated limy rocks, all of which follow the regional northeast structural trend.

Nearly all outcrops of the metadiorite are deeply weathered; most are crumbly iron-stained massive brownish-gray rocks characterized by abundant large reddish garnets. A minority of the weathered outcrops, however, are devoid of the garnets. Spotted Mountain, which is situated partly within the confines of the stock, was probably named for the garnet-spotted outcrops along its eastern portion and southern flank. The fresh rock is very coarsely crystalline, medium-gray and massive, and liberally peppered with garnet porphyroblasts up to 15 mm in diameter.

Three minerals, plagioclase (An40 ±), almandine-pyrope garnet, and biotite, constitute more than 80 per cent of the rock. Fifteen other minerals are present in amounts ranging from 4 per cent to less than 0.1 per cent. The entire rock has been metamorphically reconstituted to a low-rank granulite facies without any observable metasomatic effects. The percentages of major oxides (calculated from modal analyses) indicate a low silica content (50–51 per cent) and a 1/1 ratio for Al_2O_3/Fe-oxides + MgO + CaO.

The imposed metamorphic paragenesis implies a rather basic parent diorite whose emplacement preceded the maximum regional metamorphic facies.

RELATIONSHIP BETWEEN STRATIGRAPHY AND THE OCCURRENCE OF HIGH-ALUMINA MERCER CLAY IN WESTERN PENNSYLVANIA

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Stratigraphic and petrographic study of 25 sections of the Mercer and Connoquenessing formations in western Pennsylvania has shown that certain consistent relationships exist between the

presence or absence of high-alumina Mercer clay and the lithology, petrography, and cross-bedding of underlying, outcropping sandstones. In sections where flint or diaspore clays are present, the clay is underlain by 0–150 feet of fine- to medium-grained, very light-gray sandstone (Lower Connoquenessing ?) which consists mainly of quartz, chert, kaolinite, minor muscovite, and a heavy-mineral suite of tourmaline, zircon, and rutile. Cross-bedding dip direction is to the southwest. In sections where plastic clay or silty claystone occur below the Mercer coal, the clay is underlain by 20–165 feet of fine-grained to conglomeratic, medium-gray to medium-light-gray sandstone (Upper Connoquenessing ?) which is composed of quartz, micaceous and chloritic rock fragments, and a heavy-mineral suite of tourmaline, zircon, rutile, chlorite, biotite, and apatite. The cross-bedding dip direction is generally to the north.

The distribution of the high-alumina clay is believed to be related to ancient topographic highs where flint clay was deposited directly on the Lower Connoquenessing sandstone. The Upper Connoquenessing sandstone was deposited in adjacent topographic lows, whereas the flint clay still present on the topographic highs was leached to form diaspore.

Areas where the Upper Connoquenessing sandstone is thin or absent would be the most favorable regions for further prospecting for high-alumina Mercer clay in western Pennsylvania.

EFFECTS OF UNDERGROUND NUCLEAR EXPLOSIONS ON TUFF AT NEVADA TEST SITE

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The effects of the Rainier (1.7 kt at a scale depth of 660 ft/kt $^{1/3}$), Logan (4.5 at 500) and Blanca (23 at 290) explosions on tuff were determined from observations and measurements on the surface and in drill holes and tunnels.

Rock slides above the explosion points were the most obvious surface effects. Rock displacements took place mainly along pre-explosion fractures and were observed at distances from the explosions of 3000 feet on the surface and 2500 feet in tunnels.

Below the Rainier chamber a hemispherical breccia zone about 75 feet in radius was found. The breccia contains angular blocks of tuff in a pulverized matrix which contains droplets and fragments of radioactive glass. The glass contains the bulk of the fission products and seems to be restricted to the breccia zone. Beyond the breccia, for a radial distance of at least 110 feet from the chamber, the tuff is minutely fractured and is characterized by low compressive strength, low dilatational velocity, and high permeability. One year after the explosion temperatures greater than 2°C. above normal extended 120 feet horizontally and 80 feet vertically from the chamber. Integration of anomalous temperature data indicates that more than half the energy in the explosion remains in the form of heat. The temperatures probably dropped below the boiling point of water a few hours or days after the explosion because of the rapid transfer of heat by steam through explosion-produced and natural fractures.

REGRESSIONS OF PHYSICAL CONSTANTS ON THE CHEMICAL COMPOSITION OF PYROXENES

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Least-squares solutions for the 66 regression coefficients a_{ip} of 11 different physical properties y_p on 5 selected chemical variables x_i that define the principal constituents of clinopyroxenes yielded gratifyingly small residual differences between observed and calculated data, although part of the satisfaction over their smallness is factitious because only 10 analyses with complete physical data were available in the literature. The regressions represent the crystallographic axial lengths and the

angle β, the specific gravity, and the refractive indices and 2V. The s_p in every case is about equal to the precision of the primary data.

Analyses were recalculated to atoms per 6 oxygens; these were assigned in order of increasing sizes to fill the positions C, B, and A in the chemical formula type ABC_2O_6 of pyroxene, giving $(Si)_C$, $(Al)_C$, etc., in position C; $(Al)_B$, $(Fe''')_B$, etc., in B; and so on, for a total of 15 variables. Not all are independent, and several can be grouped with others. The independent variables finally selected were $(Si)_C$, $(Al + Fe''' + Ti)_B$, $(Mg)_B$, $(Fe'' + Mn)_A$, and $(Ca)_A$; the variables dependent upon these for space and valency reasons are $(Al + Fe''')_C$, $(Fe'' + Mn)_B$, $(Mg)_A$, and $(Na + K)_A$. Grouping Al with $(Fe''' + Ti)$ is undesirable for the optical properties, for which the regression equations of Hori (1954) may be preferred.

REGIONAL PATTERN OF PRECAMBRIAN MICROJOINTS IN THE MIDDLE ROCKY MOUNTAINS

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The orientation of 50 microjoints was plotted for each of 125 stations in the basement rocks of an area bounded by the Bighorn and Wind River ranges of Wyoming and the Little Belt and Madison ranges of Montana. Microjoints are here defined as any group of four or more subparallel fractures having a spacing of 3 mm or less. This definition resulted in a much simpler joint pattern at a station and commonly emphasized the most prominent macrojoints of an outcrop. The common pattern of microjoints is two near-vertical sets of fractures at approximately right angles and having essentially uniform orientation in any one area. A composite plot of the maxima for all stations indicates northeast- and northwest-trending microjoint sets to be the most common. The microjoints are best developed in massive granitic rocks in which thin section reveals parallel fractures and planes of fluid inclusions. The Precambrian age of microjoint formation is established only in the Clarks Fork Canyon, Wyoming, where the microfractures control the injection of quartz veinlets which are in turn truncated by the sub-Cambrian surface. The cause of regional development of microjoints is unknown but may be analogous to the origin of "rift" and "grain" of other granites. During Laramide deformation the microfractures have controlled some fault locations, have provided planes for slip folding of basement, and by their orientations indicate only minor rotation of basement along the mountain fronts.

CRYSTAL SYNTHESIS BY REFRIGERATION

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Maser operation requires crystals containing paramagnetic ions such as chromium or nickel in minute percentages which substitute generally for cobalt, aluminum, or magnesium. Crystals of $K_3Co_{.495}Cr_{.005}(CN)_6$ have been grown in freezer compartments at temperatures of $-5°$ to $+5°C$. Seeds for crystals are inserted in solutions that are saturated at about 0°C. in the freezer. Controlled quantities of solutions that are saturated at room temperature are periodically introduced into the freezer solution. The desired effect is that the growing crystals will adsorb all precipitating ions above the saturation level to eliminate additional spontaneous seeding. Daily turning of the crystals is conducive to homogeneous growth. Growth rates have been measured. Small crystals have a faster growth rate per unit weight but a lesser mass accumulation per unit time than larger crystals. Space restrictions are the only limitations on the maximum size that can be developed. Single crystals as large as c = 12.5 cm, b = 4.3 cm, a = 3.1 cm have been prepared during a 3-month growing period.

CLEAVAGE AND THE IDENTIFICATION OF MINERALS

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Mechanical etching of substances gives a characteristic pattern that can serve as a means of identifying unknown minerals and other crystalline materials. The surfaces of single crystals can be ground in several ways, with coarse abrasives; the "microcleavage pits" obtained can then be investigated by the "light figure" method. Sharp, diffuse spots and zonal reflections make up the pattern observed. The spots correspond to plane cleavages ("macrocleavage"), and the zones correspond to cylindrically curved "microcleavages". A center of symmetry is introduced into every pattern, because in cleavage and microcleavage the two newly created surfaces match.

Minerals and synthesized materials of various kinds have been investigated, and their patterns have been recorded. These patterns are arranged according to structural relationship; similar patterns have been found for members of identical structure groups. Charts of these patterns, when arranged according to crystal systems and structures, will aid in the identification of unknown crystalline materials. Among the groups investigated were pyrites, marcasites, sphalerites, wurtzites, barites, halites, and chrysolites.

MODAL ANALYSES OF THREE "QUARTZITES"

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Twenty specimens from single localities of the Tuscarora, Oriskany, and Homewood quartzites from Central Pennsylvania were point-counted with 4 traverses of 100 points per thin section per specimen. The compositional elements of the 3 quartzites were grouped into quartz, quartzose rock fragments, micaceous rock fragments and matrix, and silica cement.

The mean amounts of quartz are: Tuscarora 77.86%, Oriskany 94.57%, Homewood 70.09%. The frequency distributions differ markedly and indicate variations in arrangement. The probability of occurrence of quartz from traverse to traverse in the Oriskany is constant, and this contrasts with the extreme variability from traverse to traverse in the Homewood. This random distribution of quartz in the Oriskany implies a uniform texture (massive), whereas the distribution of quartz in the Homewood is systematic (layered). In the Tuscarora the scale of the layering is different, *i.e.*, more layers per unit area where the unit area is a thin section.

The distributions of quartzose rock fragments (mean amounts: Tuscarora 0.86%, Oriskany 0.70%, Homewood 15.93%) and the micaceous rock fragments and matrix (mean amounts: Tuscarora 5.66%, Oriskany 1.24%, Homewood 9.48%) support this conclusion.

The distribution of silica cement (mean amounts: Tuscarora 14.51%, Oriskany 1.93%, Homewood 3.69%) is independent of the quartz grains. Estimates of frequency per traverse are randomly distributed in the Homewood, whereas in the Tuscarora and Oriskany they are systematic and vary from layer to layer.

This compositional arrangement reflects two independent processes—deposition of detritus and precipitation of cement.

GRAVITY ANOMALIES ON SEAMOUNTS

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During the 1958 cruise of COMPASS ISLAND in the North Atlantic, continuous gravity measurements were obtained over three seamounts: the Cruiser Seamount, the Caryn Seamount, and an

unnamed seamount on the northern slope of the Bermuda Pedestal. These observations were made with the Graf Sea Gravimeter. Utilizing the seismic-refraction data on Cruiser Seamount and employing two-dimensional computation techniques, the depth of the M discontinuity was estimated at slightly more than 20 km beneath the seamount as compared to a depth of about 10 km below sea level under the surrounding ocean area. This depression of the M discontinuity points to isostatic compensation of the seamount. The shape of Cruiser Seamount is elongated, and it is shown that a two-dimensional form of analysis is adequate. Three-dimensional analysis is used for the Caryn Seamount and the seamount near Bermuda. The depth to the M discontinuity obtained under them and their isostatic compensation are discussed.

PRECAMBRIAN GEOLOGY OF THE MINNESOTA-ONTARIO BORDER REGION

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The geology of the Minnesota-Ontario border region has been controversial since Lawson defined the Coutchiching as a sedimentary sequence at the base of the Precambrian. The upper 5000 feet of the Coutchiching is exposed in Rice Bay of Rainy Lake where originally paragneisses were mistaken in part for granite and mapped as Laurentian. Thousands of square miles of the border region is underlain by metasedimentary rocks, gneisses, and migmatites derived from the Coutchiching. The metasedimentary rocks are chemically and mineralogically similar to more recent eugeosynclinal deposits.

Deposition of the Coutchiching was followed closely by the accumulation of a thick succession of Keewatin volcanic rocks. Coutchiching and Keewatin rocks were folded, and plutons of Laurentian granite were emplaced. Erosion of the resulting mountain belts supplied a large part of the post-Keewatin sedimentary rocks. Unroofing of the anticlinal high areas exposed the tonalites that contributed boulders to the conglomerates of the Knife Lake in Minnesota and the Seine in Ontario. Continued subsidence and folding forced the Coutchiching and its basement to great depth where melting produced magma.

Later uplift and consequent erosion of covering rocks, largely Knife Lake or Seine, exposed the Algoman gneisses (2.5–2.6 b y). The gneisses are typically in the almandine amphibolite facies; higher-level remnants of the Knife Lake and Seine are in the greenschist facies. Shearing, faulting, and local mineralization of the Laurentian tonalites and older rocks in the marginal belts occurred during the uplift. At this time postkinematic granites (2.4 b y) were intruded.

SYSTEM Ni-As-S

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Phase relations in the system Ni-As-S were determined between 500° and 700°C. All experiments were made in evacuated sealed silica-glass tubes; therefore, a vapor was always in equilibrium with the condensed phases. The vapor pressure, dependent on the bulk composition and temperature, ranged from a few millimeters to several atmospheres at 700°C. This system is characterized by extensive solid solution of arsenic and sulfur in many of the phases. Above 600°C. a complete mix-crystal series exists between niccolite and the high-temperature form of $Ni_{1-x}S$. Below 600°C. there is a break in this series, and near the crest of the solvus the width of the two-phase field increases greatly with a small decrease in temperature. A large variation in the As/S ratio is possible in the only ternary phase, gersdorffite (NiAsS). This solid-solution series is confined to the join from NiAsS toward rammelsbergite ($NiAs_2$), and from NiAsS toward vaesite (NiS_2). The composition of gersdorffite in equilibrium with rammelsbergite or pararammelsbergite varies with temperature, and

since this assemblage is common in most nickel sulfide deposits, the solvus is a potential geologic thermometer. Between NiAsS and vaesite the solvus has not been completely determined because of slow reaction rates. Limited solid solution of sulfur is also possible in rammelsbergite and maucherite ($Ni_{11}As_8$), as is that of arsenic in the high-temperature form of Ni_3S_2. Ternary assemblages stable at 500°C. correspond closely to those found in nature, which indicates that there are no major tie-line changes below this temperature.

LABORATORY PRECIPITATION OF DOLOMITIC CARBONATE

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Carbonate materials yielding X-ray-diffraction patterns characteristic of the dolomite-type carbonates have been precipitated from solutions in the laboratory. This dolomite-type material has been produced at standard pressure and at temperatures and digestion periods that are much less than those previously reported in the literature. Starting materials included calcium nitrate, magnesium sulfate, and sodium carbonate. The maximum concentration of each reagent was 1.5M. X-ray patterns made after substitution of other salts (for example, magnesium chloride for magnesium sulfate) showed no reflections from dolomite-type material. Results of experiments, including those in which the order of addition of reagents was changed, indicate that the presence of sulfates may be essential to the precipitation of the dolomitic carbonate and that the rate of reaction that affects the formation of the dolomite precipitate may be controlled by the insolubility of certain of the reactants. If the sulfates or the rate of reaction as controlled by the insolubility relations are important to the precipitation of "primary" dolomite, the genesis of dolomite, both in evaporite and other environments, may be more clearly explained.

EARLY STAGES OF EVAPORITE DEPOSITION

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Geologically important phases in the system $CaSO_4$-NaCl-H_2O include gypsum, anhydrite, halite, and aqueous solution. Except for the carbonates, this system encompasses most of the early evaporite salts encountered in nature.

Many evaporite deposits have in common (1) thick, monomineralic beds of gypsum, anhydrite, and halite (in order of older to younger); (2) alternating beds of these salts, in addition to a carbonate. A mechanism of steady-state precipitation from an evaporating ocean current is proposed to explain these features. If the hydrographic and bottom conditions are constant, then at any given spot a particular salt will precipitate out of the current, independent of the passage of time, and a thick monomineralic bed may result. This bed will also be areally extensive since generally a range of solution compositions can remain in equilibrium with a given phase. Precipitation in a closed system would result in progressively more complex mineral assemblages, but in an open system, with current motion and therefore continuous fractional crystallization, in general only monomineralic deposits could ensue. The identity of the phase may vary from place to place along the current, as temperature and pressure change; nevertheless contacts between these deposits should be sharp.

Unlike the reflux theory, this mechanism requires no restricted channel leading to the depositional basin and thus avoids the problem of dispensing the dense saline water accumulating at the bottom.

PROBLEM OF THE HORTONVILLE FORMATION IN WEST-CENTRAL VERMONT

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The Hortonville formation of west-central Vermont is largely a black-slate unit. Its Late Trenton age assignment was based on correlation with the Snake Hill formation, separated from the Hortonville formation by major faults, and on the underlying fossiliferous Glens Falls limestone near Hortonville village. Dale's graptolites in the black slate have not been authenticated, and the localities yielded no new specimens.

Recent mapping in the Lower Cambrian allochthonous Taconic sequence immediately south of Hortonville shows that the contact between the type Hortonville and the Glens Falls may be a fault. The type Hortonville slate was traced into an outcrop from which Schuchert reported *Olenellus* (?) fragments; both stratigraphically and geometrically, the type Hortonville corresponds to the Lower Cambrian black slate of the Taconic sequence, and in the field no contact is discernible between them. The Hortonville is also reported as traceable into fossiliferous Upper Trenton black slate in the Middlebury synclinorium. Available evidence, including exotic blocks of Taconic rocks embedded in Trenton black slate, indicates that the Taconic sequence moved into the Upper Trenton sea as submarine slides. The tectonic commingling of the two units may make the delineation of their contact inherently impossible. The writer urges that the name Hortonville formation not be used with time connotations.

Complete understanding of the contact relations and geometric patterns within the black-slate unit now called Hortonville, surrounding the Taconic sequence, may offer the solution to the Taconic problem.

GEOPHYSICAL AND GEOLOGICAL INTERPRETATION OF A TRIASSIC STRUCTURE IN EASTERN PENNSYLVANIA

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Interpretation of aeromagnetic data for a recent air-borne magnetic survey leads to a clearer understanding of the structure of the Triassic basin near Doylestown, Pennsylvania, where faulting exposes the pre-Triassic floor and causes a repetition of the entire sequence of Triassic rocks.

The Furlong (Flemington) fault, which brings pre-Triassic rocks to the surface at Buckingham Mountain and Buckingham Valley, has an apparent stratigraphic throw of about 10,000 feet. Lower Cambrian and some Precambrian rocks are exposed on Buckingham Mountain, and the Precambrian rocks are sufficiently magnetic to cause a strong anomaly the full length of the mountain. Analysis of this anomaly indicates that the throw on the Furlong fault is probably not more than 3000 feet, although there is probably additional throw on the extension of the Chalfont fault and possibly on other faults. The pre-Triassic floor apparently slopes south between the Furlong fault and the Chalfont fault; this suggests that the Buckingham area was already a topographic high in pre-Triassic time.

Aeromagnetic data indicate that the upper surface of the Precambrian north of Buckingham Valley slopes to the northwest not more than 30°, approximately parallel to the overlying sedimentary rocks. The absence of an abrupt change in slope of the Precambrian surface suggests that no major Paleozoic-type structure was present here in Triassic time.

IMPROVED CLASSIFICATION OF SILICATES

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The conventional Machatchki-Bragg classification of silicates is losing its usefulness as the number of determined silicate structures increases, partly because it fails to provide sufficient detail and partly because it does not prescribe a consistent treatment for the various tetrahedrally co-ordinated cations. The lack of detail can be corrected by considering additional geometric characteristics of the silicate structures. Two such characteristics are: (1) the sharing coefficient, which is a numerical measure of the corner sharing of the tetrahedra and is also related to the cation-anion ratio of the chemical formula; and (2) the numbers of tetrahedra in the structural loops, which represent the basic linkage of tetrahedra and are related to the energies of the structures.

A large number of silicates can be classified differently depending on whether we consider all tetrahedra of the structure or only the silicon and aluminum tetrahedra. This problem is not treated consistently in the literature. In some cases aluminum tetrahedra are disregarded (cordierite, gehlenite) or other tetrahedra, like boron, are accepted (danburite). The writer suggests that all tetrahedrally co-ordinated cations should be considered part of the tetrahedral frame of a silicate. This suggestion is supported by the similarity of the observed ionic radii and electronegativity of other four-coordinated cations to that of silicon and aluminum, and by the analytical data indicating the random distribution of silicon and other cations in different tetrahedra of certain silicates.

RELATIVE ENERGIES OF RINGS OF TETRAHEDRA

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When the structure of coesite became known it was natural to compare it with the other known structures of silica. In the comparison it became evident that the structures of quartz, tridymite, and cristobalite are composed of 6-membered loops of tetrahedra, the intermediate-pressure keatite is composed of 5-membered loops, and the high-pressure coesite contains 4-membered loops. The stability fields of these structures, and hence their energies, are readily correlated with the sizes of their loops. This prompted an inquiry into the relative energies of loops of various sizes. Computations were made for symmetrical rings similar to the beryl ring but containing, in general, n tetrahedra. It was assumed that the tetrahedra contained central ions of $+4$, vertex ions of -2 if shared, or -1 if unshared (giving a neutral ring). The 5-membered rings had a minimum energy, and 6- and 4-membered rings had somewhat more energy. Other rings have relatively high energies. These findings are consistent with the structures of known forms of silica as well as common silicates.

ABSTRACTS OF PAPERS SUBMITTED FOR THE MEETING IN TUCSON, ARIZONA, APRIL 2–6, 1959

CORDILLERAN SECTION (GSA), PACIFIC COAST SECTION (PS), AND SEISMOLOGICAL SOCIETY OF AMERICA

CORRELATIONAL STUDY OF EARTHQUAKE WAVES

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(On leave from Tokyo University)

Waves due to local earthquakes, detected by a temporary net of vertical seismometers placed on granitic rocks near Mt. Tukuba in Japan, are recorded on a multi-channel magnetic recorder. The recorded waves having the frequency range 2 cps to 20 cps are analyzed by a correlational method which gives us information about the direction and velocity of propagation of regular plane waves as well as their power relative to the coexisting irregular noises in any portion of the waves. The analysis was made automatically by means of a specifically designed electronic computer.

This kind of study is essential, if one wants to make use of the whole seismogram instead of few particular phases for purposes such as locating small earthquakes and estimating earthquake energy. It is natural to expect that information involved in the whole seismogram is greater than that in the wave form at the commencement of some phases.

It was found that the regular plane wave has a comparable power to irregular noises in the wave portion for the first several seconds after the initial motion, and gives us greater accuracy in the determination of direction of propagation than the initial motion only as it is used in the conventional way. The fraction of power carried by the plane wave is greatest in the initial wave portion, decreases later, becomes slightly larger at the arrival of *S* wave, and is very small in the wave portions after *S* wave. The nature of waves at various portions of the seismogram will be discussed in some detail.

It is important to make the above study on local earthquakes at various places. The writer, with the co-operation of staffs of the Earthquake Research Institute, has made the study at two places, Kamakura and Mt. Tukuba, in Japan, and is undertaking one at Mt. Palomar in California with the aid of the California Institute of Technology.

EVIDENCE FOR A TROPICAL CENTER OF ANGIOSPERM EVOLUTION

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The global, spatial relations of Early Cretaceous floras show that in the Northern Hemisphere angiosperms invaded lowland basins at low–middle latitudes during the Necomian; middle to mid-high latitudes in the Aptian; and high latitudes only in the Aptian-Albian transition and in the Albian. In the Southern Hemisphere they had reached only middle latitudes by Albian time.

This general poleward migration of angiosperms during the Early Cretaceous can be explained by the theory that they had their general center of origin at lower, tropical latitudes during the pre-Cretaceous, as suggested earlier on the basis of evolutionary and distributional evidence provided by Late Cretaceous and Cenozoic flowering plants.

Since relict Jurassic-type vegetation persisted at high northern and at middle southern latitudes well into the Cretaceous (Albian), and was replaced by angiosperms there only following the Cenomanian, it is apparent that age analysis of Cretaceous floras must take into consideration time–space relations analagous to those shown by Tertiary forests. The time–space factor involved in the poleward migration of angiosperms during the Cretaceous explains most of the conflicts, which have persisted for nearly a century, in the testimony of age supplied by fossil plants and marine invertebrates.

GEOLOGIC SIGNIFICANCE OF COILING RATIOS IN THE FORAMINIFER *GLOBIGERINA PACHYDERMA* (EHRENBERG)

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Studies of Recent populations of the planktonic foraminifer, *Globigerina pachyderma* (Ehrenberg), show that more than 98 per cent of Arctic and Antarctic specimens coil in a counter-clockwise (sinistral) direction, whereas populations in temperate and tropical regions are about 98 per cent clockwise (dextral) in manner of coiling. Basin cores off southern California show that the modern dextral forms have persisted for about 11,000 years and were preceded by sinistral populations in the late Pleistocene, as determined by radiocarbon dating. Investigation of populations in Pliocene and Pleistocene strata of southern California show consistent sinistrality in the Pleistocene and in the middle part of the Pliocene. Assemblages from the upper and lower Pliocene are dominantly dextral. Thus, an additional stratigraphic tool is provided for improving the accuracy of Late Cenozoic correlations of southern California.

PASSIVE NETWORKS FOR SEISMOGRAPHS

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Resistance-capacitance passive networks having equivalent period-response characteristics of galvanometers have been constructed for use in long-period strain and pendulum seismographs. The range of equivalent periods has extended from 75 seconds to 10 minutes. In all cases the long-term stability of the networks has been superior to that of galvanometers of equal periods. The networks are being used with both ink and heated stylus recorders.

STRUCTURAL CONTROL OF QUICKSILVER ORE AT THE RED DEVIL MINE, ALASKA

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The Red Devil mine, Alaska's largest quicksilver producer, is in the central Kuskokwim region, about 250 miles northwest of Anchorage. The ore mineral is cinnabar, which is associated with abundant stibnite.

Detailed mapping indicates that most ore bodies are localized at intersections between altered dikes of Tertiary age and bedding-plane faults in thin- to medium-bedded graywacke and shale of the Cretaceous Kuskokwim group, an interpretation first recognized by John D. Murphy, former manager and geologist at the mine.

The dikes, which strike northeast and dip southeast, are offset in en echelon pattern by right-lateral strike-slip faults that strike northwest and dip southwest. Ore bodies are localized in breccia and shear zones at the intersections of the dike segments and faults, and locally they replace near-by parts of the dikes. Most of the known ore bodies form a series of steeply plunging, subparallel, rod-like lodes, which rake 35°–80°S., in the fault planes.

At least three mineralized dikes are recognized which consist of hydrothermally altered basalt or andesite. The faults are clean-cut slips or gouge and breccia zones. Movement along them was mainly strike slip, but subordinate dip-slip movements are indicated. Apparent fault displacements range from less than an inch to about 20 feet.

SEISMIC STUDIES OF CRUSTAL STRUCTURE IN THE EASTERN BASIN AND RANGE PROVINCE

Joseph W. Berg, Jr., Kenneth L. Cook, and H. D. Narans, Jr.

Preliminary results are presented of seismic studies of quarry blasts at Promontory Point and Lakeside, Utah, during 1956 to 1959, and the Blanca nuclear explosion near Mercury, Nevada, on October 30, 1958.

Neglecting the effect of superficial sediments, the time–distance plot of first arrivals from Promontory Point, Utah, to Eureka, Nevada (nearly 360 km), shows the following approximate velocities: 5.7 km/sec. to approximately 80 km, 6.3 km/sec. from 80 to 130 km, and 7.6 km/sec. from 135 to 360 km. The data are interpreted provisionally to indicate two velocity discontinuities, one at a depth of about 9 km and another at a depth of approximately 25 km.

The time–distance plot of first arrivals for the Blanca nuclear explosion, which was obtained from four stations in northern Utah at distances between 380 and 660 km from the shot point, shows a velocity of 7.4 km/sec. for the recognizable first arrivals of energy.

The observed velocities are somewhat less than the normal velocities recorded for the upper portion of the mantle. The large horizontal distances over which these velocities were observed suggest that any material having a velocity of approximately 8.0 km/sec. would of necessity be deeper than about 45 km as computed from the Promontory Point profile and about 60 km as computed from the Mercury profile. The latter is contrary to observations made by Carder and Bailey (1958).

If these observed velocities of 7.4 to 7.6 km/sec. can be interpreted as attributable to material constituting the upper portion of the mantle, then the fact that they occur beneath the eastern part of the Basin and Range province may be of tectonic significance.

GLACIAL GEOLOGY ON THE EASTERN AND WESTERN SLOPES, SIERRA NEVADA, CALIFORNIA

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Seven glacial advances, in three groups, are recognized in the San Joaquin drainage, western slope Sierra Nevada, and in Rock Creek on the eastern slope. Glacial advances are distinguished largely on geomorphic criteria involving abrupt changes in aspect of subsequent erosion, deposition, and weathering. Quantitative data are provided mostly by granite-weathering ratios and, to some extent, boulder-frequency counts. Statistical analysis shows that the weathering-ratio counts confirm correlation from canyon to canyon and across the crest of the Sierra.

The earliest glacial deposits recognized, those of Group I, are found wholly outside areas of younger ice advances. Weathering is extensive but is markedly less than in areas not recognized as glaciated. Few morainal forms are still present, and locally there are granitic erratics on lava. The deposits are believed to be Sherwin in age.

Three advances are recognized in Group II, the oldest and youngest of which are Tahoe and Tioga, respectively. Intervening is a hitherto unrecognized advance, here given a new name. It is recognized in the San Joaquin drainage, in the Yosemite Valley, and in several canyons on the east side of the Sierra. Deposits of Group II are abundantly evident throughout middle elevations.

The Hilgard advance, the oldest of Group III, reached several miles from the cirques and is characterized by a sharp reversal in weathering ratio. It is believed to be later than the Thermal Maximum. The succeeding Recess Peak deposits are within or near the cirques, and, although very fresh, the slopes are stabilized. Tree-ring counts indicate a minimum of 250 years in age. The Matthes deposits consist mainly of cliff glacierets and rock glaciers still unstable. The entire Group III is interpreted as Neoglacial.

WASATCH FAULT IN CENTRAL UTAH

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Recent mapping of the Wasatch fault zone in central Utah, particularly east of Utah Valley, demonstrates that the footwall is the most active element and that throughout the length of an area from Mt. Timpanogas on the north to Mt. Nebo on the south much of it has responded as a normal upthrust. Precise dating of initiation of movement has not been possible in this area, but probably it has been active since Oligocene time at least and possibly is seismically as active now as before. Plane-table mapping on scale of 1:1200 along a segment of the fault zone east of Provo reveals numerous details of the frontal fault in which bedrock has been uplifted, disrupting Pleistocene sediments and dragging some of them up. Sediments of the Lake Bonneville group, in some localities, have been carried up on the footwall as much as 200 feet above the elevation at which they were deposited.

Inclination of the fault-line scarp is commonly 35° W.; in places movement that is post-Provo stage of Lake Bonneville is relatively high angle, and at a few localities the fault plane dips 80°E. On one of these, upper Precambrian graywacke conglomerate has been upthrust over sediments of Wisconsin Lake Bonneville group. Observed fault planes, some on bedrock and some on Pleistocene sediments, commonly display dip-slip movement; a few, of different age movement, show oblique slip. Normally, dip of the fault plane of these is 60–80°W.

Numerous faults cut Lake Bonneville and associated Quaternary sediments in the piedmont area. A few faults which displace bedrock of the footwall block also extend into the Quaternary sediments; most recent movements of the Wasatch fault offset these.

CORRELATION OF LATE PLEISTOCENE EVENTS BY RADIOCARBON DATING

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Radiocarbon dating has allowed the correlation of events occurring in widely separated geographic localities and in a variety of geologic environments. Over the past several years an attempt has been made to relate the Great Basin climate changes, which are well recorded by the fluctuation in the sizes of the closed basin lakes, with climate-controlled changes in other systems. One of the most interesting conclusions drawn from this study is that each system studied shows strong evidence of rather abrupt climate change close to 11,000 years ago.

In the Great Basin radiocarbon dates on carbonate materials deposited at the level of the high shore lines of Lake Lahontan suggest a high stand of the lake close to 11,800 years ago, while dates on organic materials from wave-cut caves indicate that the lakes had fallen to nearly their present level by 11,000 years ago.

The evidence for a similar event in other systems includes: an abrupt warming of the surface waters of the Atlantic Ocean, sharp changes in rates of oceanic sedimentation, pronounced warming in pollen profiles, and rapid retreat of continental glaciers all close to 11,000 years ago.

Reaching back more than 11,000 years the results suggest a more or less continuous cold period extending to 25,000 years before present. Prior to this, evidence from continental glaciers and the ocean is in accord with that from the Great Basin lakes in suggesting a period of intermediate conditions. The beginning of this interstadial period is not well defined by radiocarbon work nor are the events preceding it.

FRAGMENTAL ACID INTRUSIVE IGNEOUS ROCKS OF THE SOUTH COMOBABI MOUNTAINS AND KO VAYA HILLS, PIMA COUNTY, ARIZONA

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The South Comobabi Mountains and Ko Vaya Hills occupy an area of about 80 square miles in southern Arizona, about midway between Tucson and Ajo.

The basement rocks consist of a diorite complex intruded by quartz monzonite. These rocks are overlain by andesitic lavas and coarse clastic sedimentary rocks, and both together reach a maximum thickness of about 19,000 feet. They are tentatively classified as Cretaceous and Tertiary. The quartz monzonite and some of the lavas are cut by hypabyssal intrusives, partly fragmental in structure, and similar in composition to the quartz monzonite. These later intrusives form a series that includes granophyres, felsite, microbreccia, pebble dikes, and breccias. Crosscutting relationships and inclusions indicate consolidation of the magmas between periods of intrusion.

An approximate sequence of intrusives, inferred from field relationships, is as follows: (1) maroon quartz latite porphyry with contact facies, (2) alaskite microbreccia, (3) rhyolite granophyre with pebble dike facies, (4) quartz latite porphyry with intrusive breccia facies.

The alaskite microbreccia contains rock fragments that consist predominantly of alaskite, but the fragments in the three facies listed above are of diverse composition. All the fragmental rocks, however, have a microcrystalline matrix of alkali feldspar and quartz. The writer postulates that the magma, in the case of the microbreccia, permeated but did not appreciably displace an intensely fractured body of alaskite, while in the other three types the magma swept through and carried along various kinds of country rock.

PHYSICAL AND TEXTURAL FEATURES OF DEPOSITS ASSOCIATED WITH NEAR-SURFACE SUBSIDENCE IN WESTERN FRESNO COUNTY, CALIFORNIA

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Land-surface subsidence due to compaction of near-surface deposits has been observed in about 100 square miles along the west edge of the San Joaquin Valley, Fresno County, California. Locally the total subsidence is more than 10 feet, and subsidence rates of as much as 0.25 foot per day have been measured in test plots.

The subsidence is caused chiefly by irrigation water percolating through certain alluvial-fan deposits for the first time. In these relatively dry deposits the amount of compaction is dependent on the overburden load, the clay content, and the texture, which becomes more compact as the advancing water front weakens the clay bond. Tests on representative surface samples indicate that maximum compaction occurs when the clay content is about 12 per cent. If less than this amount is present the dry overburden load will tend to have compacted the sediment already. If there is more than about 12 per cent clay the swelling of the montmorillonite fraction, upon addition of water, will reduce the net compaction. The percentage of clay was determined from grain-size analyses made with a minimum disaggregation of shale fragments.

Some openings that tend to contract upon addition of water to a sample under load are: (1) intergranular openings between grains held in place by a dry clay bond; (2) bubble cavities formed by air entrapped at the time of deposition; (3) interlaminar openings in thinly laminated sediments; (4) open, yet buried, polygonal cracks; and (5) voids left by decomposition of entrapped vegetation.

The polygonal cracks occur chiefly in mudflow deposits, and the interlaminar openings occur only in water-deposited sediments. The other features are found in both types of sediments.

ERUPTION OF MARCH 5–6, 1958, OF MANAM VOLCANO OFF THE NORTH COAST OF NEW GUINEA

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G. A. Taylor, Australian volcanologist, uses with high success seismological evidence together with triggering action by spring tides of the earth to predict renewed volcanic activity in the Territory of New Guinea. Manam is one of the volcanoes under his surveillance. It forms an almost cir-

cular island about 8 miles off the north coast of New Guinea, 6–7 miles in diameter and more than a mile high. Late in 1957 this volcano came to life after a decade of quiescence.

The 3000 inhabitants were evacuated soon after renewed activity began, which was quite timely because shortly thereafter a nuée ardente burst out of the south flank of the volcano and destroyed one of the villages. Renewed bursts of activity seemed to coincide with the spring tides, and, at the time of the author's visit in Rabaul in late February 1958, an eruption was successfully predicted for March 5–6, during the full moon. High activity began on March 5 with a nuée which nearly reached the sea and a shower of mud and cinders which fell upon Mr. Taylor and the author as they were checking an observation post. This activity continued for 30 minutes and then changed in form. Incandescent rocks, visible from the sea, were thrown vertically above the crater, and at night the beginning of a lava flow could be seen from the sea, as could the bomb fountain which was quite spectacular, and which before dawn had reached an estimated height of 6000 feet above the crater. On March 6, the volcanic cloud had reached an estimated height of 20,000 feet above the crater, and the lava flow had reached the sea with explosive violence. The eruption was accompanied by almost continuous seismic activity and pulsating ground tilts. By May 1958 activity had died down, and the natives were returned to their devastated homes on the island.

SEISMIC-WAVE TRAVEL TIMES FROM NUCLEAR EXPLOSIONS—PART II

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Since publication of the first paper on this subject, a wealth of seismic data as a result of the 1958 nuclear explosions in the Pacific and in Nevada has been accumulated. In the Pacific area more than a dozen new stations in Australia, New Zealand, and New Guinea have been added, and others including the Caroline Islands stations have been added or improved. In Nevada, underground explosions in the 5 to 20 kt range have made possible continent-wide recording and beyond. Many organizations have participated in the latter series because the times of detonation and the approximate yields had been made public prior to detonation. Not all the data have yet been assembled, but the available data more or less support some earlier concepts of the earth's interior and modify others. Noteworthy are the anomalous behavior of *PcP* in the 30- to 65-degree distance ranges, sharp cutoff of P_n between 94° and 97° because of the core shadow and apparent low-energy zone in continental areas at distances of about 30°, and the strengthening of the concept of the regional shadow zone at distances of 10° more or less.

LUDWIGITE FROM FRESNO COUNTY, CALIFORNIA

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Ludwigite has been found at two localities on the north side of Kaiser Ridge, eastern Fresno County, California. One of these, known as the Potter Pass locality, was studied in detail, but the second, the Kaiser Peak locality, has received a preliminary investigation only. At the Potter Pass locality, ludwigite, the magnesium-iron borate, occurs in brucite marble where it is associated with magnetite, diopside, forsterite, periclase, brucite, spinel, clinohumite, and an unidentified mineral containing copper and boron. At the Kaiser Peak locality, the ludwigite is associated with magnetite, diopside, and forsterite in a narrow band of granular dolomitic limestone which is interbedded with lime-silicate hornfelses composed of wollastonite, grossularite, diopside, and vesuvianite.

At both localities the ludwigite occurs as individual needlelike crystals which range in length from 2 to 10 mm and up to 3 mm across and in felted masses of hairlike crystals. The ludwigite has a glossy-black luster and is transparent on thin edges. A comparison of the specific gravity of the Fresno County ludwigite with the specific gravities of analyzed ludwigites from worldwide localities indi-

cates that the Fresno County material is much nearer the magnesian end of the ludwigite series than the ferroan end (paigeite).

A study of the ludwigite-bearing rocks indicates an early formation of forsterite, diopside, spinel, and periclase (brucite) followed by a later formation of clinohumite, ludwigite, and magnetite.

TYPE LANCE FORMATION AND ITS MAMMAL FAUNA

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The type Lance formation, exposed near Lance Creek, Wyoming, consists of approximately 2000 feet of dark shales and buff to brown cross-bedded sandstones. This formation as defined by Hatcher included the dinosaur-bearing beds that overlie the marine Fox Hills sandstone. Upper and lower limits of the formation corresponding to those defined by Hatcher on primarily biostratigraphic criteria can be defined on lithostratigraphic criteria alone.

According to the most recent age assignments based on fossil invertebrates, the type Lance formation lies on Maestrichtian marine sediments and is overlain by continental sediments which interdigitate with Danian marine sediments north of Lance Creek. Since no assemblages of fossil mammals of latest Cretaceous or earliest Tertiary age have been found in western Europe the Lance mammals cannot be used at present for a more precise correlation with the European standard. The type Lance formation must be regarded as being a correlate of the Maestrichtian and/or Danian.

Special washing and screening procedures used by University of California field parties have added many new types of small vertebrates to the fauna of the Lance formation. In addition to various types of small mammals, some larger, terrier-sized mammals are also represented. Apparently late Cretaceous mammals were more abundant and diverse than is commonly believed. This sample of fossil mammals can be used as a basis for comparison and correlation of samples drawn from other Rocky Mountain sedimentary units.

CHAPALA FORMATION, JALISCO, MEXICO

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A considerable number of fossil mammal bones have been recovered from the floor of Lake Chapala, which is a large fresh-water lake about 35 miles south of Guadalajara in Jalisco, Mexico. In order to determine whether or not the bones had come from a series of sedimentary beds on the northern shore of the lake, the writer mapped the beds in the fall of 1956. The name Chapala "beds" was given them by Palmer in 1926.

The Chapala "beds" consist of several hundred feet of sediments striking northwest and dipping about 20° NE. Shale and claystone are the most abundant rock types, although sandstone, fine conglomerate, marl, diatomite, and ash beds are common throughout the section. Occasional beds consisting of water-worn pumice particles of pebble size are striking lithologic types. A basal conglomerate rests on rhyolite of probable Miocene age, and the formation is beveled above by a series of lake terraces.

Fossils collected from the formation include ostracods, fish, turtle, mastodon, peccary, and at least two genera of horses. The fossil mammals are being studied by Dr. Theodore Downs of the Los Angeles County Museum, and, although the study has not been completed, the indications are that the age of the formation is early Pleistocene or possibly transitional Plio-Pleistocene. No evidence was found to indicate that the fossils found on the present lake floor had come from the Chapala "beds".

STRATIGRAPHY AND STRUCTURE OF BARE MOUNTAIN, NEVADA

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The Paleozoic rocks at Bare Mountain are typical of the eastern Nevada facies and consist dominantly of carbonate rocks with Lower Cambrian and Upper Mississippian clastic rocks. The Paleozoic rocks have been intensely deformed, principally by flat thrust faults and right-lateral strike-slip faults. The thrust faults, in part folded, occur mainly in the weak shaly parts of the section; locally these shaly rocks are strongly imbricated.

Tuffs and welded tuffs of Tertiary age have been thrust over the Paleozoic rocks. The Tertiary volcanic rocks were tilted and fractured when these rocks were thrust over the older rocks, but the deformation was less intense than that in the earlier thrust plates in Paleozoic rocks. Basin and Range normal faults developed in late Tertiary and Quaternary time, and one of these faults probably bounds the east side of Bare Mountain. Other normal faults offset Recent fanglomerates.

STRATIGRAPHIC HISTORY OF THE LANGLEY HILL—WATERMAN GAP AREA, SANTA CRUZ MOUNTAINS, CALIFORNIA

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Detailed mapping (1:24,000) in the Langley Hill–Waterman Gap area in the northern Santa Cruz Mountains, California, reveals a section of discontinuous rock-stratigraphic units up to 20,000 feet thick.

Deep marine conditions in the Santa Cruz basin in the early to middle Eocene produced foraminiferal claystones of the Butano (?) shale. The overlying Butano sandstone represents middle to late Eocene basin filling with a thick blanket of immature sand. Continuous sedimentation during latest Eocene, Refugian, and Zemorrian ages deposited the persistent San Lorenzo shale and its Zemorrian shallow-water equivalent, the Vaqueros sandstone.

Submarine vulcanism during the Zemorrian age erupted basaltic flows and palagonitic breccias, which intercalated with the Vaqueros sandstone and overlying strata, and intruded a sill of diabase into the San Lorenzo shale. Mudstones of Zemorrian and Saucesian age, previously mapped as Monterey shale, intertongue with and overlie the Vaqueros and volcanic rocks. These have been renamed Sandholdt formation because of similarities with the type section of that formation in the Santa Lucia Mountains. Relizian Monterey siliceous shales were deposited unconformably (?) on the Sandholdt formation and in turn unconformably overlapped by Pliocene Purisima tuffaceous and diatomaceous sandstones and mudstones. Locally Plio-Pleistocene Santa Clara gravels were washed unconformably over older strata.

Structurally the area is a downwarp. Numerous northwest-striking, locally overturned folds and reverse faults have resulted in crustal shortening of several miles. Steeply dipping Pleistocene strata indicate recent orogeny.

CRUSTAL STRUCTURE IN THE NORTH PACIFIC FROM LOVE-WAVE DISPERSION

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The Love waves from the earthquake of June 22, 1952, in the Kurile Islands give dispersion data that is used in estimating the crustal structure of the North Pacific. Observed periods in the Love-wave train for this earthquake vary continuously from 25 to 8 seconds. Crustal models that agree with the observed dispersion consist of 2 km of material with an *S*-wave velocity of 2.31 km/sec and 4 km of material with an *S*-wave velocity of 3.71 to 3.86 km/sec overlying material with an *S*-wave velocity of 4.5 km/sec.

These models are similar to a model used by Evernden for the Pacific Basin. Thinner layers are

required to explain the observed dispersion along this North Pacific path than were required for the path investigated by Evernden.

STRUCTURAL RELATIONSHIPS OF CHURCH CREEK AND WILLOW CREEK FAULTS, SANTA LUCIA RANGE, CALIFORNIA

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The core of the northern Santa Lucia Range southeast of Monterey consists of metamorphic and granitic rocks upon which thin sequences of Upper Cretaceous and Tertiary sedimentary rocks rest unconformably. Sedimentary rocks occur principally in isolated, elongate exposures adjacent to major faults.

Church Creek fault (dip 65° NE.) is one of a system of major northwesterly trending high-angle reverse faults of probable Pliocene age. Adjacent to the fault on the southwest is a parallel homocline of Eocene and Oligocene (Refugian) strata that dip northeast and rest unconformably on crystalline rocks. A regionally consistent parallelism of major reverse fault traces with adjacent downfaulted homoclines or synclines of sedimentary rock suggests that the reverse faulting was genetically related to the development of folds with crystalline rocks in their cores.

Church Creek fault terminates on the southeast at Willow Creek fault (strike E.-W., dip vertical), which acted during the Pliocene as an oblique-slip tear fault transverse to Church Creek reverse fault. Earlier displacement on Willow Creek fault during the early Eocene offset at least 1000 feet of Paleocene strata and dates a period of diastrophism that may be of regional importance. Subsequent early Eocene erosion removed Paleocene rocks from the upthrown north side of Willow Creek fault, and younger Eocene rocks were later deposited there on crystalline rocks. However, a north-dipping homocline of Paleocene strata that rest unconformably on crystalline rocks was preserved adjacent to the fault on the south.

STUDY OF SHEAR-VELOCITY DISTRIBUTION IN THE UPPER MANTLE BY SURFACE-WAVE ANALYSIS. PART I: MANTLE RAYLEIGH WAVES

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Comparison of the mantle Rayleigh-wave dispersion observations of Ewing and Press with computations on Rayleigh-wave dispersion shows that Gutenberg's solution for distribution of shear velocity in the mantle and other similar solutions which have a region of low shear velocity in the upper mantle are in satisfactory agreement with the dispersion data.

Furthermore, these computations and others on hypothetical shear-velocity distributions empirically define the relation between the velocity distribution and the dispersion curve to the extent that the mantle Rayleigh-wave observations can be analyzed in terms of mantle structure. By this approach two interesting conclusions are established. (1) The minimum-group velocity observed at 225 seconds period is mainly due to a relatively sharp downward increase of shear velocity at depths of 400 to 500 km, a prominent feature of body wave solutions. (2) A downward decrease of shear velocity must begin at much shallower depth below the M discontinuity in order to satisfy the shape of the observed dispersion curve between periods of 75 and 200 seconds. Thus surface-wave analysis provides independent confirmation of the conclusion which was originally reached from body-wave data that a region of low shear velocity exists in the upper mantle.

SCUTELLASTER OREGONENSIS IN THE PACIFIC COAST PLIOCENE

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In 1958 Durham and Wolf recorded the occurrence of *Scutellaster oregonensis quaylei* (Grant and

Hertlein) in association with *Dendraster gibbsii* (Rémond) in the uppermost Jacalitos formation. Subsequently Mr. R. M. Touring verified Martin's and Kew's reports of this generic association in the Purisima formation. The echinoids occur in the same bed at a point approximately 0.6 mile south of the mouth of Tunitas Creek along the sea coast south of Half Moon Bay. This is within the "upper sandstone" as that term was used by Martin and others.

Examination of topotypes of *S. oregonensis* indicates that the characters used to distinguish the variety *quaylei* [*gibbosus* of Kew] are not significant taxonomically and that the latter as well as the variety *semigibbosus* Howe does not merit separate designation. The species *S. oregonensis* in this sense is now known in California from the uppermost Jacalitos, the upper Purisima, the lowermost type Merced, the Rio Dell formation of the Wildcat group, the Falor formation, and the unnamed Pliocene north of Little River, Humboldt County. In Oregon it occurs in the Coos conglomerate, the Port Orford formation of Cape Blanco, and in Washington in the Montesano formation. In Alaska, specimens collected by D. J. Miller of the U. S. Geological Survey from the "interbedded marine sandstone and siltstone" unit of the Pliocene of the Lituya district represent this species.

It is suggested that an approximate middle Pliocene age can be assigned to these occurrences.

FOSSIL OCCURRENCES BEARING ON THE FRANCISCAN PROBLEM IN CENTRAL CALIFORNIA

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Three new localities for significant fossils have recently been discovered in rocks previously assigned to the Franciscan formation. S. C. Bruff and students found *Inoceramus schmidti* (Michael) of Campanian age in black shale about 1½ miles south of Novato, and Edgar H. Bailey of the U. S. Geological Survey collected *Inoceramus labiatus* (Schlotheim) of early Turonian age and *Buchia piochii* (Gabb) of Late Jurassic age near Skaggs Springs, California (sec. 24, T. 10 N., R. 11 W., and sec. 9, T. 9 N., R. 11 W., respectively). Robert L. Rose also found *Buchia piochii* (Gabb) near Novato.

Although rocks containing these fossils have in the past been assigned to the Franciscan formation, their relationship to Franciscan rocks in San Francisco, generally regarded as the type locality, is unknown, and more field work is required before the significance of the fossils can be established.

Buchia piochii occurs also in beds mapped as Knoxville formation on the east side of San Francisco Bay from Berkeley to near San Jose. *Buchia crassicollis* (Keyserling) of Early Cretaceous age occurs in beds overlying the Knoxville throughout the same area. In at least one locality in the Hayward quadrangle the Knoxville formation is reported to overlie unconformably rocks mapped as Franciscan, and the same relationship has been suggested in north Berkeley. This indicates that some of the beds called Franciscan are older than the Late Jurassic Knoxville and some are as young as Late Cretaceous.

MAJOR TECTONIC CHANGE IN SOUTHWESTERN PART OF NORTH AMERICAN CONTINENT IN BELTIAN TIME

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Precambrian orogenic belts are becoming better defined as absolute dates become more numerous and widespread. A prominent belt 1300 to 1400 m.y. old extends from Arizona to South Dakota and perhaps farther. It was reflected strongly by the transcontinental arch in early and mid-Paleozoic time. The oldest rocks of the continent (2200 to 2700 m.y.) extend in a broad belt from Labrador to western Wyoming and Montana and emphasize the southwest-northeast trend of the 1300 to 1400 m.y. zone.

In Beltian time a trough developed parallel with the present continental margin and distinctly

discordant with the older (1300–1400 m.y.) orogenic belt. A post-Beltian—Precambrian orogeny followed in the site of the Beltian trough. Late Paleozoic orogeny followed in a belt adjacent on the west. This is the Antler and Shuswap orogenic belt. Still later the Nevadan orogeny occurred in a wide belt west of the previous orogenic belts; it makes substantially the present continental margin.

It appears evident, therefore, that a major change in the southwest margin of the continent occurred in Beltian time. We may consider that a major part of the southwest margin as it existed in pre-Beltian time is missing, but no plausible theory of translation or foundering has been conceived to restore the missing part. The concept of growth of the continent by the successive addition of orogenic belts about a central nucleus in pre-Beltian time may also be questioned. It is conceivable that a major change occurred in the constitution and assembly of the continents in the interval of time immediately preceding the Beltian.

RELATIONSHIP OF THE PELONA SCHIST AND VINCENT THRUST IN THE SAN GABRIEL MOUNTAINS, CALIFORNIA

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Pelona schist of greenschist facies is semiconcordantly overlain by gneiss, migmatite, and quartz diorite of amphibolite facies within the eastern San Gabriel Mountains, California. The contact between rocks of the two facies is tectonic in origin and is called the Vincent thrust. Because the thrust developed within a metamorphic environment, it lacks gouge, megascopic breccia, and slickensided rupture surfaces.

The lower 200 feet of the hanging wall of the thrust consists of schist containing augen of relic hornblende and feldspar in a recrystallized matrix of greenschist-facies mineralogy. Gradationally overlying this are cataclastic rocks which grade upward into little affected rocks of amphibolite facies. The zone of cataclastic and retrograde rocks is as much as 1500 feet thick.

Crystalloblastic Pelona schist forms the footwall. Cataclastic textures and evidence of retrograde metamorphism are lacking, even at the thrust contact. Metamorphic deformation and crystalloblastic grain size increase structurally upward toward the thrust. Lineation including that produced by parallel growth of prismatic minerals is parallel to lineation in the overlying retrograde schist. A highly developed schistosity parallels bedding in the Pelona schist and subparallels the Vincent thrust.

All evidence indicates that metamorphism of the Pelona schist occurred syntectonically with development of the Vincent thrust. It is speculated that burial beneath the thrust induced metamorphism.

Reconnaissance indicates that a similar thrust relationship exists in other areas of Pelona and Pelona-like schists within southern California.

"DEGRANITIZATION" OF THE NORTHERN INYO RANGE, CALIFORNIA–NEVADA

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The Pellisier granite, which became a classical example of granitization after G. H. Anderson's 1937 article on the northern Inyo Range, consists of several units. These units include metamorphic schists and gneisses as well as two distinctive plutons of granodiorite. The granodiorite portions of the Pellisier granite are generally separated from the sediments by aureoles of medium-grade contact metamorphism only a few feet thick rather than by broad transitional zones. The "pseudosedimentary structure in granite" described by Anderson is related to repeated movement on a recent fault and is not relict sedimentary bedding.

Granitic plutons of the McAfee Ranch quadrangle portion of the Inyo batholith, California–Nevada, are in sharp intrusive contact with each other and with the surrounding sediments. These

bodies were intruded in an increasingly more felsic sequence; the adamellites contained altered portions of the earlier granodiorites. Variations between plutons, both modal compositions and normative compositions calculated from modes, are directly related to the experimentally located thermal valley which controls the compositions of liquids in the system SiO_2-$NaAlSi_3O_8$-$KAlSi_3O_8$. There are only small areas of migmatites, and these are regarded as by-products of magmatic intrusion. It is apparent that this classic area of "extensive" granitization can no longer be cited as evidence of the metamorphic origin of granite.

STRUCTURAL RELATIONS IN THE PEDREGOSA AND SWISSHELM MOUNTAINS, COCHISE COUNTY, ARIZONA

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The Pedregosa and Swisshelm mountains trend northwest and border the eastern margin of the southern Sulphur Spring Valley in southeastern Cochise County, Arizona. They are 25 miles north-northeast of Douglas.

Paleozoic and Mesozoic sequences in these ranges compare with those in the Mule and Dragoon mountains (Ransome, 1904; Gilluly, 1956), flanking the western margin of the Sulphur Spring Valley. Unconformities at the base of Upper Devonian and Lower Cretaceous strata reflect widespread epeirogenic movements which affected southeastern Arizona and southwestern New Mexico.

The principal orogenic structures of the Pedregosa and Swisshelm mountains originated during late Cretaceous–early Tertiary time. Paleozoic and Mesozoic strata were folded and locally overturned to the southwest along gently plunging axes having northwesterly trends. Cogenetic reverse and thrust faults strike northwest and dip northeast; upper plates of major thrusts moved at least several miles from northeast to southwest. One such thrust extends 14 miles along the southwestern fronts of the ranges and coincides with the boundary separating them from the adjacent valley.

During late Tertiary time each range was broken into separate structural blocks by differential vertical movements along steep, north-trending normal faults.

Analysis of structural symmetry and associated movements in the ranges bordering the southern Sulphur Spring Valley indicates that it is a basin whose structure, like that of surrounding mountains, is more closely related to late Cretaceous–early Tertiary folding and thrusting than to late Tertiary normal faulting.

CENOZOIC TIME SCALE OF THE WEST COAST

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The suggested time scale of the Cenozoic of the West Coast as determined by potassium-argon dates on sanidine, biotite, glass, and glauconite is as follows:

	Age (years)
Post-Tioga stage volcanism	ca. 6000
Early Mono Craters	ca. 65,000
Early Sierran glaciation (Lower Pleistocene)	1,000,000
Base of Pliocene	12–13 million
Base of Miocene	25–27 million
No Oligocene defined in marine sequences, but continuous deposition	
Base of Kreyenhagen	ca. 36 million
Base of Eocene	48–50 million
Base of Paleocene	55–60 million

It is suggested that the Upper Eocene (*i.e.*, Kreyenhagen) is the time equivalent of the Oligocene of the Gulf Coast.

CRUSTAL STRUCTURE IN THE CARIBBEAN FROM SEISMIC MEASUREMENTS

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Seismic-refraction studies in the Caribbean have shown wide variation in structure and thickness of the crust. In general, the crust is thin under the deeps, thick under the ridges, and intermediate in between, as might be expected if the area is approximately in isostatic balance. The deepest water inside the island arc is in the Cayman Trough, and the crustal structure there closely resembles a typical ocean-basin section. In the deeper parts of the Venezuelan, Colombian, and Yucatan basins the crust is slightly thicker but still similar to oceanic crust. Away from the deepest parts of the basins the crust thickens to 20–25 km under the Aves Swell, Beata Ridge, and Nicaraguan Rise, and probably is close to continental thickness under the islands. In several profiles, where the measurements have been uncomplicated and sufficiently detailed, it has been possible to see an increase in velocity with depth in the crustal material from 6.0–6.5 km/sec near the top to 7.0–7.5 km/sec at the bottom. The material above the main crustal layer has a wide range of velocity—from 1.8 to 6.0 km/sec. In general, the deeper areas have a greater thickness of the low-velocity material, and the ridges and intermediate areas more of the higher-velocity material. These data show that the Caribbean as a whole is intermediate between continental and oceanic structure, although some parts are very nearly either continental or oceanic.

LAKE DEPOSITS IN WESTERN UNITED STATES

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Four maps of 11 western States show: (1) known and inferred lacustrine deposits of pre-Tertiary age; (2) known and inferred lacustrine deposits of Paleocene and Eocene age; (3) known and inferred lacustrine deposits of Oligocene, Miocene, and Pliocene age; and (4) areas occupied by lakes during some part of Pleistocene time. Formations shown on the first three maps are grouped as follows: those known to be wholly or largely lacustrine in origin; those including known lake deposits; and others that may be lacustrine in part.

Areal distribution of the strata suggests a geographic center of Mesozoic lakes along a strip extending from Arizona to Montana; a small number of large Paleocene and Eocene lakes in Washington, Oregon, Wyoming, Colorado, and Utah; widespread distribution of smaller lakes later in Tertiary time; and a noteworthy shift in concentration of Pleistocene lakes toward the southwestern part of the area considered.

Alinement of Pleistocene lakes in southeastern Arizona, southwestern New Mexico, and Mexico suggests that the southern edge of the Colorado plateau is controlled by a structural trough extending from Lakes Santa María and Guzmán in Chihuahua, Mexico, northwestward about 500 miles to Grand Wash Cliffs, Arizona; 40 miles of the Colorado River upstream from the cliffs falls within the inferred trough.

The maps represent a preliminary compilation and are offered for comment. They will accompany a review and annotated bibliography now in preparation.

PROGRESSIVE REGIONAL METAMORPHISM AND MIGMATIZATION OF THE CAIRN RIDGE CRYSTALLINE SCHISTS, NEAR JUNEAU, ALASKA

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A 20,000-foot section of crystalline schists is exposed in continuous outcrop along the crest of Cairn Ridge, near Juneau, Alaska. The sequence trends northwest and is isoclinally folded and overturned to the southwest; consequently schistosity dips to the northeast. Schistosity is mainly

parallel to compositional banding, but divergence occurs in the axial zones of major folds. The grade of progressive regional metamorphism increases northeastward across the strike, including mineral assemblages of low, medium, and high grades.

A wide variance in composition of the intercalated rock units permits the comparative study of metamorphic zonation and facies in basic volcanic rocks and argillaceous and impure calcareous-dolomitic sedimentary rocks under conditions of progressive synkinematic metamorphism.

Zones are clearly defined in the alumina-excess rocks, which faithfully duplicate the zonation of the Grampian Highlands described in the classic works of Barrow and Tilley. The zonal distribution of index minerals in the calcium- and magnesium-rich intercalations reconfirms the reliability of Barrovian zonation based on pelitic schists.

Plagioclase shows a systematic increase in anorthite content with rising metamorphic grade.

Migmatitic gneisses appear in the kyanite zone and occur with increasing frequency toward the northeast as a result of the transformation of amphibolites and pelitic schists. Plagioclase composition, percentage, and textural development indicate that migmatization was accomplished by the selective metasomatic introduction of sodium and silica during synkinematic metamorphism.

The Cairn Ridge study is an integral part of an investigation of the Coast Range batholith which will be completed in June 1959.

FOSSIL PLANTS FROM THE CANADIAN ARCHIPELAGO

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Collections of fossil plants obtained during Operation Franklin of the Geological Survey of Canada have provided considerable new data on floras in the Canadian Arctic. The specimens indicate a range of time from the late Devonian to the Pleistocene. All the localities are within the Arctic Circle and extend to 81° N. Lat.

Sediments on Prince Patrick Island yielded *Callixylon*, *Enigmophyton*, cf. *Protolepidodendropsis*, and *Bothrodendron* indicating the Late Devonian. No new Late Devonian species were obtained from the Okse Bay section on Ellesmere Island. Cornwallis Island provided a spore microflora identified by Radforth as containing 17 forms including *Cirratriradites* and *Endosporites*. These forms indicate mid-Pennsylvanian. The largest contribution to knowledge of paleofloras came from Mesozoic sediments. *Clathropteris meniscoides*, *Laccopteris*, *Dictyophyllum*, *Ptilophyllum*, and *Anomozamites* from several localities on Axel Heiberg Island suggest a Rhaetic age. These floras are correlated with those of Scoresby Sound in Greenland. Padloping Island yielded remnants identified by Bose (1955) as a bennettitalean leaf, a ginkgo leaf, and *Sciadopitys variabilis*. The latter form occurs chiefly in the latest Jurassic and early Cretaceous of the Arctic. Amund Ringnes and Axel Heiberg Island sediments yielded specimens of woods of early Cretaceous age belonging to *Piceoxylon*, *Cedroxylon*, and *Phyllocladoxylon*. From near Eureka near 81° N. Lat. the paleoflora included *Osmunda*, *Metasequoia*, and *Cercidiphyllum*. This flora is considered to be early Tertiary in age, probably Paleocene or early Eocene. Pleistocene or later sediments from Banks Island provided specimens representing vast accumulations of secondary xylem (wood) of *Abies*, *Pinus*, and *Thuja*. These data from the Canadian Arctic paleofloras provide fundamental information concerning the relationship between floras of Europe, Greenland, and Asia.

ENGINEERING GEOLOGY IN PLANNING AND CONSTRUCTION OF TRINITY RIVER DIVERSION, CALIFORNIA

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Construction has been underway almost 3 years on the quarter billion dollar project to store and divert surplus water of the Trinity River Basin into the upper Sacramento Valley. The earth-fill Trinity Dam, 515 feet high, will provide storage of 2,500,000 acre-feet. The water will then flow

through a system of re-regulating reservoirs, tunnels, and power plants to develop power from a total drop of about 1800 feet from Trinity Reservoir to Sacramento River. Geologic studies embracing a wide variety of techniques have been made in progressively greater detail at all stages of planning, designing, and now of building this major addition to the Central Valley Project.

LEFT-LATERAL FAULTING IN OWENS VALLEY, CALIFORNIA

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At the time of the great earthquake of 1872 in Owens Valley, California, there was faulting and fissuring for a distance of 75 miles. There was both vertical and horizontal displacement. Considerable confusion exists as to the relative direction of the lateral movement. A review of the literature, and investigation in the field, indicates that the dominant horizontal movement was left lateral.

PERIOD OF MINERALIZATION OF THE COMSTOCK LODE, NEVADA

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The Comstock Lode, in western Nevada, was one of the most productive gold and silver deposits in the United States. Various opinions have been expressed as to the age of the mineralization, ranging from Middle Miocene to late in the Cenozoic.

The geologic column in the Comstock region is as follows:

Age	*Formation*	*Lithology*	*Maximum thickness (Feet)*
Pleistocene	McClellan Peak	Olivine basalt	25
		Unconformity	
Pliocene	Knickerbocker	Basaltic andesite flows	400
		Unconformity	
	Coal Valley (Truckee)	Lacustrine volcanic sediments, diatomite, and breccia. Lower part interbedded with Kate Peak	3000
	Kate Peak	Upper—Hornblende-pyroxene-biotite andesite agglomerates, breccias, some flows and intrusive plugs	2000
		Lower—North of the district a rhyolitic vitrophyre is the basal member	2000
		Unconformity	
Oligocene	Alta	Upper—Hornblende-pyroxene andesites. Mostly flows, some breccias	2600
		Sutro member—Volcanic sediments, some breccias	400
		Lower—Hornblende-pyroxene andesite breccias with some flows	600
Eocene (?)	Hartford Hill	Rhyolitic pyroclastic rocks. Commonly welded tuffs	1000
		Unconformity	
Pre-Cretaceous (Triassic ?)		Metasediments and metavolcanics	2000

The pre-Cretaceous rocks were intruded by Sierran granodiorite. The Davidson granodiorite intruded the Alta and older formations. The gold- and silver-bearing quartz veins are most abundant in the Alta but are found also in the Davidson granodiorite and pre-Cretaceous rocks. Fragments of the Davidson granodiorite are enclosed in the quartz of some of the veins.

A long period of erosion beveled the mineralized formations, and the Davidson granodiorite rises as a monadnock above the erosion surface. The Kate Peak formation lies upon that surface. It contains no quartz veins.

The ores were introduced after the emplacement of the Davidson granodiorite and before the deposition of the Kate Peak volcanic rocks. The mineralization occurred in Miocene time, probably Middle Miocene.

CAYTONIALEAN MICROSPORES FROM THE JURASSIC AND CRETACEOUS OF ALASKA

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Caytonanthus-type microspores are reported for the first time in Mesozoic sediments of North America, outside of Greenland. The grains are remains of an extinct order of gymnosperms, the Caytoniales, which flourished abundantly and had cosmopolitan distribution during the Jurassic, although their foliage occurs from the Upper Triassic to the Upper Cretaceous. The microspores are found at two widely separated localities in Alaska: (1) the southwestern Peninsula region in Marine sediments ranging from Lower to Upper Jurassic, and (2) from the Arctic Coastal Plain, south of Wainwright, in coals and shales tentatively considered upper Lower to lower Upper Cretaceous.

The microspores are coniferouslike, with two, symmetrically opposite bladders broadly attached to the body. Their dimensions are conspicuously small—size-frequency measurements indicate an overall extreme of less than 40 microns—and distinguish them from pollen of living gymnosperms of like morphology and from similar winged grains of the Mesozoic. The Alaskan caytonialean populations are compared with those of three closely similar species described from the Jurassic of Greenland and England. Although several factors may have been operative, the differences demonstrated are considered natural and suggest taxonomic distinctions.

Population counts indicate that the microspores are most abundant in the Lower Jurassic, where they may constitute about 50 per cent of the microflora. In the Lower Cretaceous, they are nowhere more abundant than 17 per cent of the population; in sediments of probable Late Cretaceous age, they are absent or represent less than .3 per cent of the microflora, indicating in all probability extinction in the northern area.

GEOLOGY OF THE MAZOURKA CANYON AREA, INDEPENDENCE QUADRANGLE, INYO COUNTY, CALIFORNIA

J. L. Greife, R. W. Nelson, H. R. Pestana

Outcrops of Ordovician Pogonip dolomite, Mazourka formation, Barrel Springs formation, undifferentiated Eureka group, and Ely Springs dolomite; unnamed Silurian limestone and shale; Mississippian White Pine shale; and Pennsylvanian Keeler Canyon formation are widespread throughout the area. Permian Owens Valley formation crops out only in the southern portion. The Pogonip dolomite and post-Silurian formations were not studied in detail. Dissected terraces of Quaternary alluvium cover most of the canyon floor. Granitic intrusives form the ridges bordering most of the area on the east and lower ridges west of the canyon.

Paleozoic rocks dip west at high angles forming the western limb of a large northwest-trending anticline. A small syncline and minor thrust fault at the Betty Jumbo Mine and minor folds adjacent to the western intrusive in the northern part of the canyon modify the major anticline. Small transverse faults are widespread.

The Mazourka formation, predominantly limestone with a basal shale, contains Chazyan fossils. The Barrel Spring formation is a thin detrital unit with middle Ordovician fossils. Interbedded quartzite, limestone, and dolomite form the undifferentiated Eureka group. The carbonates are

largely replaced southward by quartzite and contain late Middle to Late Ordovician corals. The Ely Springs dolomite is almost unfossiliferous. Silurian rocks are bounded by disconformities. The limestone facies in the south contains a late Middle to Late Silurian coral fauna and is replaced by graptolite-bearing shale within approximately 4 miles in the lower part of Mazourka Canyon.

ENGINEERING GEOLOGY OF BLACK BUTTE DAM SITE, STONEY CREEK, CALIFORNIA

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The proposed Black Butte Dam is a Corps of Engineers flood-control structure under design by the Sacramento District, Sacramento, California. It is to be located on Stoney Greek (a tributary of the Sacramento River), which drains a large area on the eastern slope of the California Coast Range. Although minor irrigation benefit will be realized, the principal value of the project will be flood protection to the city of Orland and its surrounding area of agricultural lands.

Principal items of interest to engineering geologists are stratigraphic sequence of foundation rocks which range from basal Cretaceous shales through Pliocene sediments to Plio-Pleistocene basalt flows; baked, surcharged mudstones beneath the abutment caprock basalt, which feature open "fractures" conducive to high water loss; rebounded mudstone beneath the stream bed which disclosed preloaded plastic silts which have closed pre-existing fractures.

Exploration has disclosed that the basalt caprock dips laterally from each abutment, leading to conditions of maximum strength from natural orientation. Although grouting of the mudstone will largely satisfy seepage conditions in the abutments, water loss under hydraulic head may well be a serious factor in the mudstones of the stream bed. This problem, induced by the presence of open gravel lenses conducive to downstream uplift, will be met by the post-construction emplacement of relief wells.

DISPLACED MIOCENE MOLLUSCAN PROVINCES ALONG THE SAN ANDREAS FAULT, CALIFORNIA

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Assuming that present-day temperature and other ecologic requirements for molluscan genera and species are generally the same for most taxa that lived in the past, and that organisms are critically limited in distribution by minimum temperatures, then some thermal limits may be inferred for the Late Miocene molluscan faunas in the Coast Ranges of California. By plotting the present positions of Late Miocene paleo-molluscan provinces and isotherms, provincial and temperature differences are apparent on either side of the San Andreas fault at the same latitude. The distance between the same isotherm or provincial boundary on opposite sides of the fault is approximately 120 miles.

Because of the subjectivity of locating the Late Miocene molluscan provinces and isotherms, this means of measuring the amount of separation along the San Andreas fault gives only an approximate order of magnitude; the minimum and maximum separations are 50 and 150 miles respectively.

GEOHYDROLOGY OF ARIZONA

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Arizona contains three water provinces: (1) Plateau uplands of the northern part of the State; (2) Central highlands, the central mountainous area; and (3) the Basin and Range lowlands of the southwestern half of the State.

The main aquifers in the Plateau uplands are the Coconino sandstone of Permian age, which underlies nearly all the area; the Navajo sandstone of Jurassic and Jurassic(?) age, a wedge-shaped formation; and the Mesaverde group of Cretaceous age, which includes a series of sandstone, silt, and shale units. This series of water-bearing fine-grained sandstones forms a large storage reservoir but does not yield large amounts of water.

The core of the Central highlands consists of igneous and metamorphic rocks. The northern peripheral area contains Paleozoic sedimentary rocks. The hard, dense rocks are extensively fractured and faulted, and small amounts of water are stored in these breaks. Springs issue from many of the faults.

The Basin and Range lowlands consist of impervious mountain blocks and intervening alluvial basins. Three major types of deposits occur in alluvial basins: (1) coarse conglomeratic material lies on the basement rocks; (2) clayey and silty lake deposits form thick, widespread units in most basins; and (3) clay, sand, and gravel form the upper unconsolidated part of the sediments. The coarse sediments have a large storage capacity and yield water freely to wells.

About 5 million acre-feet of ground water is withdrawn annually, mostly from the alluvial basins. As annual recharge is small, ground-water reserves in Arizona are being depleted.

EXPERIMENTAL AND THEORETICAL STUDIES OF METHODS FOR OBTAINING VELOCITY VARIATIONS IN TWO-DIMENSIONAL MODELS

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Two-layer plates with varying thicknesses of plastic and aluminum are used to obtain velocity variation in a two-dimensional seismic model. Theoretical relationships between velocity and layer thickness are compared with experimental data.

Preliminary work on Rayleigh-wave dispersion is described.

STRATIGRAPHIC RELATIONSHIPS OF THE WHITETAIL AND GILA CONGLOMERATES NEAR RAY, ARIZONA

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The Whitetail conglomerate was tentatively assigned an early Tertiary age by Ransome (1919). North of Ray, Arizona, the unit overlies Precambrian schist and is conformably overlain by a dacite flow. The dacite is conformably overlain by alluvial deposits referred to as the Gila conglomerate of Pliocene and Pleistocene age. Ransome assigned a Tertiary age to the dacite and a Quaternary age to the Gila.

The dacite represents a single flow deposited during a short time. Near Ray, the Whitetail and Gila conglomerates are essentially conformable, and no evidence for an appreciable erosional interval is recognized between the dacite and the Gila. The compositions of the two conglomerates are markedly similar. It is suggested that the Whitetail and Gila conglomerates represent essentially continuous deposition, temporarily interrupted by a dacite flow, and that the disparity in their ages assumed by Ransome is untenable.

Within the Gila conglomerate south of Ray, tuff beds crop out at a position which suggests that they correlate with the dacite. Also, the Gila south of Ray and the Whitetail 2 miles north of Ray are similar because in both units the lower beds contain predominantly Precambrian, and the upper

beds contain predominantly Paleozoic fragments. These similar changes and the tuff beds suggest that the Gila south of Ray is equivalent to both the Whitetail and Gila north of Ray.

Structural and stratigraphic relationships south of Ray in the San Pedro Valley suggest a late Tertiary age, possibly between late Miocene and middle Pliocene, for the Whitetail and Gila conglomerates near Ray.

GEOLOGY OF THE CRICKET MOUNTAINS, MILLARD COUNTY, UTAH

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More than 150 square miles, just east of Sevier Lake, was mapped by members of the 1958 Brigham Young University geology summer camp. The Cricket Mountains expose Cambrian marine formations unconformably overlain by Tertiary continental deposits. The Cambrian stratigraphy is similar to that of the House Range, 35 miles to the northwest, and includes the Prospect Mountain quartzite, Pioche shale, Busby formation, Millard limestone, Burrows limestone, Burnt Canyon limestone, Dome limestone, Condor shale, Swasey limestone, Marjum limestone, and unnamed Upper Cambrian limestones and dolomites. The Wheeler shale, famous for its trilobites in the House Range, is conspicuously absent.

Structurally the Cricket Mountains are a horst composed of a series of east-dipping tilted fault blocks. On the southeast side of the range one of the blocks consists of a broad syncline in Upper Cambrian rocks. The Tertiary, consisting in the southern part of the range mostly of a limestone breccia, and in the northern part of coarse gravels in a reddish matrix, lies with angular unconformity over the Cambrian. A pisolitic brown limestone bed, resembling Flagstaff limestone lithologically, is interbedded with the gravels in the northern part of the range.

No evidence of thrust faulting was found within the Cricket Mountains.

ORIGIN OF REMARKABLE BERYL CONCENTRATIONS IN THE HARDING PEGMATITE, NEW MEXICO

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Since 1950 the Harding mine, in Taos County, New Mexico, has yielded 840 tons of commercial beryl concentrates. Most of this output has come from a quartz-rich hanging-wall zone along the flank of a broad, thick bulge in the gently dipping main pegmatite dike. The beryl-bearing zone, 6 inches to 8 feet thick, is separated from the overlying country rock by a thin, albite-rich border selvage, and it intertongues laterally with perthite-rich pegmatite that is prominent only in the thinner parts of the dike. It is underlain by a layerlike zone of massive quartz.

The beryl occurs mainly as large anhedral crystals and crystal aggregates in association with quartz, apatite, and muscovite. It is markedly concentrated beneath gently plunging rolls in the pegmatite–wallrock contact, where it locally forms irregular masses amounting to many tens of tons. The principal rolls are 5 to 30 feet wide and 10 to 25 feet in amplitude.

The distribution, composition, and textural relationships of the beryl suggest that it is a primary and early-stage mineral in the main bulge of the dike. Its origin seems best explained in terms of "second boiling" in a crystallizing magma of granitic composition, the beryl having formed chiefly from aqueous vapor in equilibrium with the melt. Selective transfer of appropriate constituents into and through the vapor, along with some gravitative concentration of the vapor itself, might well account for development of the large crystals and their exceptional abundance beneath the crests of the most prominent hanging-wall rolls. Experimental crystallization of melts in the laboratory has demonstrated the feasibility of this mechanism.

ENGINEERING GEOLOGY IN THE CALIFORNIA DEPARTMENT OF WATER RESOURCES

Laurence B. James and Harold D. Woods
California State Department of Water Resources

The magnitude and complexity of large engineering projects such as the California Water Development Program which envisions the eventual construction and operation of 260 new major surface reservoirs co-ordinately with a similar number of ground-water basins, and the hundreds of miles of tunnels and canals necessary for conveyance of the water, requires the fullest measure of team work among many professions.

Engineering geologists of the Department of Water Resources pool their professional talents with those of hydraulic engineers, electrical engineers, economists, attorneys, physicists, chemists, and many others in attacking the fundamental problem of developing California's water resources for the people. Each of these professions is getting into unaccustomed fields of endeavor which require the knowledge and assistance of the many other professions. Engineering geologists are breaking away from the older concept of the geologist working strictly as a lone wolf, more or less independent of the many other equally important aspects of the general project, and instead are joining closely in the team effort. Geologic, engineering, and other aspects of each problem are considered concurrently through round-table discussions, and each member of the team contributes data and opinion toward solution of the common problem.

The fields of geophysics, rock mechanics, geohydrology, and seismology are being exploited. Problems in seismicity, tunnel-cost estimating, and land subsidence are subjects of research programs which are already yielding profit.

Younger geologists of the Department undergo training during the first 2 years of employment. This includes rotation among planning, design, and construction activities; on-the-job-training in inspection of sites for dams, reservoirs, tunnels, and canals; and investigation of ground-water basins and sources of construction materials.

STRATIGRAPHY OF UPPER CRETACEOUS ROCKS IN THE YREKA-HORNBROOK AREA, NORTHERN CALIFORNIA

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Upper Cretaceous rocks in the Yreka-Hornbrook area are exposed in a narrow belt extending from south of Yreka northward into Oregon. They rest unconformably on metamorphic and granitic rocks and are unconformably overlain by the nonmarine Colestin formation of Tertiary age.

The name Hornbrook formation has been applied to the entire sequence of Cretaceous rocks, but detailed mapping indicates that three major subdivisions can be recognized which may eventually be elevated to formational status. These are informally designated, in ascending order, as units A, B, and C.

Unit A is 700–800 feet thick and consists of a lower conglomeratic sandstone member and an upper sandy siltstone member. Unit B, unconformably overlying unit A, is nonmarine in part and consists of about 130 feet of massive, conglomeratic, concretionary, greenish-gray sandstone. Unit C consists of about 4000 feet of dark-gray, marine siltstone with sandstone interbeds and with a thick sandstone tongue near the base. This unit has been mapped previously as the Umpqua formation of Eocene age, but *Inoceramus* present in the upper part indicates that all of unit C is Cretaceous.

The lower member of unit A contains upper Turonian *Subprionocyclus neptuni* (Geinitz) and lower Coniacian *Prionocycloceras crenulatum* (Anderson).

Unit B contains only fragmentary plant remains.

Unit C contains a rich ammonite fauna characterized by *Metaplacenticeras pacificum* (Smith), several pachydiscid species, and abundant *Inoceramus*. The probable age of unit C is middle Campanian to Maestrichtian(?).

NEW SPECIES OF PHACOPID TRILOBITE

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The phacopid trilobite occurring in the Middle Devonian at Lone Mountain, Eureka district, Nevada, has been misidentified by previous authors as *Phacops rana* (Green, 1832). A new name is here proposed because this species possesses the following dissimilar characteristics: (1) 30 per cent more eye facets, (2) incipient genal spines, (3) an indistinct third glabellar lobe, (4) narrow ridge separating the eye from the occipital furrow, (5) distal nodes on the thororachis, (6) anterior four annulations of pygidium arched forward containing articulation nodes, (7) anterior four pairs of ribs furrowed.

CLIMATE OF THE SOUTHWEST

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Four important factors which exert an influence on climate are (1) latitude, (2) altitude, (3) moisture sources, and (4) orientation of mountain ranges. The ways in which these factors are important are discussed briefly.

There are two large high-pressure systems, the "Pacific High" and the "Bermuda High," which exert an important influence on the weather over the Southwest. The seasonal migration of these centers produces major changes in the general atmospheric circulation and in the paths followed by major storms between the cold season (October-March) and the warm season (April-September). These changes, together with the four general factors, are responsible for a large part of the climatic differences between various parts of the Southwest. These differences are pointed out and briefly discussed.

Following the description of the major climatic controls and differences over the Southwest, in general, the climate of Arizona is discussed in more detail.

CHAOTIC BRECCIAS IN THE TUCSON MOUNTAINS, ARIZONA

John E. Kinnison

The rocks of the Tucson Mountains, west of Tucson, Arizona, may be divided into two dominant groups: (1) Paleozoic and Mesozoic sedimentary rocks which were intensely deformed during the Laramide revolution, and subsequently eroded to a surface of gentle relief; and (2) Tertiary and Quaternary volcanic and sedimentary rocks which have been faulted and tilted.

A tabular breccia zone, named the Tucson Mountain chaos, lies between these two rock sequences. Its striking characteristic is that it contains very large fragments of all the pre-Laramide rocks disposed in a disoriented manner. The chaos fragments range in size from less than 1 foot to larger than 200 feet. The Tucson Mountain chaos ranges in thickness from zero to more than 400 feet but generally is about 200 feet thick. Its outcrop area is 14 by 3 miles. The dip of the chaos parallels that of the overlying volcanic rock. A boulder conglomerate occurs locally at its base, and angular conglomerates are erratically distributed internally.

The writer suggests that the Tucson Mountain chaos is a sedimentary breccia and that it rests on a post-Laramide surface of erosion, named the Tucson surface. Its origin is postulated to involve

a seismically active fault scarp to supply the fragments, which were transported and deposited by mudflow, landslide, and intermittent stream action.

Geologists have previously interpreted the chaos zone as the remnant of a large Laramide overthrust. The origin now proposed, therefore, invokes a different interpretation of the structural framework of the Tucson Mountains.

FIRST MOTIONS FROM SEISMIC SOURCES

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The conditions occurring at the initiation of earthquake faulting are examined. It is found that there are eight independent types of initial conditions of discontinuity in stress and displacement across plane faults. Any faulting occurring in nature can be given as a linear combination of these elementary types. The first motions at seismograph stations can therefore be represented as a combination of the eight basic motions resulting from faulting and from those sources (such as explosions) which may act in the absence of faulting. The *P* and *S* wave seismic radiation from all the elementary sources has been found and is not the same in all cases. The fault stress and displacement conditions can be represented by equivalent forces: sources of shear displacement must be represented by an equivalent double couple of the type suggested by Honda; sources of shear stress must be represented by an equivalent isolated force, not hitherto emphasized in the seismic literature. It is suggested that a sudden discontinuity of shear stress across a fault plane without a corresponding discontinuity in displacement may describe the initial conditions occurring in deep-focus earthquakes.

BURIED PRE-CENOZOIC ROCKS OF THE DATIL-MOGOLLON PLATEAU IN NEW MEXICO*

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The fault-block ranges, graben valleys, and volcanoes of the mountainous plateau country of west-central New Mexico consist of Neogene (Miocene-Pleistocene) volcanic and associated sedimentary rocks. Pre-Cenozoic sediments are exposed only at the edges of the plateau and in a few isolated outcrops within the volcanic fields. Exploration for petroleum or contact-metamorphic mineral deposits can be promising only where: (1) the volcanic cover is thin, and (2) favorable pre-volcanic sediments were deposited and have not been removed by subsequent erosion.

Lower Paleozoic sediments probably were deposited in the area but have been removed north of 33½ N. Lat. during erosional periods that occurred in middle Ordovician, early Devonian, and early Pennsylvanian time. Pennsylvanian and/or Permian marine strata, 1000–4500 feet thick, were deposited in the area. Locally these sediments were partially or completely removed during early Mesozoic and early Tertiary erosional periods. As much as 2000 feet of Cretaceous strata has been preserved along the northern and southern margins of the plateau. Early Tertiary erosion has differentially dissected pre-Tertiary rocks so that basal Tertiary rocks may rest on strata ranging in age from Cretaceous to early Pennsylvanian within a few miles. Despite numerous periods of erosion, pre-Tertiary–post-Precambrian beds are more than 1000 feet thick in almost all places where they crop out or have been encountered by drilling, suggesting that a like thickness may occur beneath the volcanic rocks throughout the Datil-Mogollon Plateau.

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CAMBRIAN AGE OF SOME OF THE BASAL PALEOZOIC SANDSTONE IN CENTRAL ARIZONA

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In central Arizona, two lithologically and stratigraphically different basal Paleozoic sandstones can be recognized. One sandstone everywhere underlies the lowest of four units of the Martin limestone of Devonian age. The other, of limited extent, was deposited around topographic highs of the Mazatzal quartzite of Precambrian age and interfingers laterally with the Martin limestone.

The sandstone that everywhere underlies the Martin limestone has been considered both basal Martin and a southeastward extension of the Tapeats sandstone of Cambrian age. The southernmost fossiliferous Tapeats is at Walnut Creek (Juniper Mesa). Exposures of lithologically similar but unfossiliferous sandstone are nearly continuous between Walnut Creek and Jerome. Locally, in the Paulden quadrangle, the sandstone grades upward into coarse conglomerate that, at one place, is overlain abruptly and disconformably by limestone of the basal unit of the Martin. The abrupt change in conditions of deposition is compatible with different ages of the underlying and overlying beds. The stratigraphic position and near continuity of lithologically similar sandstones support the correlation of this sandstone with the Tapeats, and its Cambrian age.

RAYLEIGH-WAVE VELOCITIES IN A VISCO-ELASTIC SOLID

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Rayleigh's wave equation for a semi-infinite visco-elastic solid (Voigt or Kelvin model) is expressed in terms of Lamé's constants for elastic and viscous elements, λ/μ and λ'/μ', and internal friction, $\omega\mu'/\mu$ or $1/Q$. The expressions of velocity for both Rayleigh and shear waves are complex. The ratios of Rayleigh-wave velocity to shear-wave velocity are calculated on the IBM 650 for a wide range of elastic and viscous parameters: (1) $\eta\lambda/\mu = \lambda'/\mu'$ for $\eta = \frac{1}{10}, \frac{1}{5}, 1, 5$, and 10; (2) Poisson's ratio σ ranging from 0 to 0.5; and (3) internal friction $\omega\mu'/\mu$ or $1/Q = 10^{-3}, 10^{-2}, 10^{-1}, 1$, and 10. Results are presented in graphic form.

The ratios of Rayleigh-wave velocity to shear-wave velocity in a visco-elastic solid for internal friction $1/Q < 10^{-2}$ are equal to the same ratios calculated by Knopoff for an elastic solid. For internal friction $1/Q > 10^{-2}$, the ratios vary in a wide range depending upon Poisson's ratio σ and the factor η in $\eta\lambda/\mu = \lambda'/\mu'$.

GEOLOGIC FRAMEWORK OF ARID BASINS IN ARIZONA

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Declining water levels in many Arizona ground-water basins indicate that pumping draft exceeds recharge. Appraisal of present and future water supplies requires greater knowledge of the geologic framework than is available for most basins. Mapping and stratigraphic studies in basins now being dissected by through-flowing drainage, coupled with detailed studies of logs and samples from wells, offer possibilities of relating gross lithologic units to permeability factors needed for hydrologic analysis.

A conventional interpretation of most arid basins is that they have been filled by erosion from adjacent mountain blocks, resulting in marginal coarse alluvial-fan deposits grading into central lake or flood-plain facies. Some Arizona basins do not seem to fit the conventional picture. Rather, in such basins, fine deposits lap onto steep marginal bedrock areas with no intervening coarse deposits, except,

in some cases, opposite mouths of major streams that entered the basins while they were being filled. These relationships suggest an external source for much of the basin fill.

In some basins, coarse sediments now exposed along the margins do not interfinger with the fine-grained deposits but lie unconformably on them, as fan or pediment gravels, and the unconformities represent much of Pleistocene time. Also, reports of great thicknesses of coarse alluvium underlying some basins are based, in part, on examination of records which do not clearly distinguish between younger, unconsolidated alluvium and the older, probably pre-Pliocene, consolidated deposits that are too impermeable to serve for water storage.

GEOLOGY OF THE WARD MOUNTAIN AREA, ELY QUADRANGLE, WHITE PINE COUNTY, NEVADA

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Ordovician and Silurian formations are confined to the southwestern corner of the area. Devonian Sevy dolomite, Simonson dolomite, Guilmette limestone, and Pilot shale crop out on the west slope of the mountains and in Robinson Canyon. Mississippian Joana limestone, White Pine shale, and Scotty Wash quartzite occur similarly but are thinner than in surrounding areas. The Scotty Wash quartzite thins northward and is absent in Robinson Canyon. The remainder of the mountains consists of Chesteran to Atokan Ely limestone, Wolfcampian Rib Hill formation, and Leonardian Arcturas formation. Here Permian limestones are generally sandy, in contrast to cherty Pennsylvanian limestones. Sandstone in the Rib Hill formation is largely replaced southward by sandy limestone. Tertiary nonmarine sedimentary and volcanic rocks border the mountains with an outlier near Murray Summit. Dikes and minor intrusives occur on the southeast slopes.

Folds trending north-northwest are widespread in the mountains, are overturned eastward, and are accompanied by a west-dipping thrust fault on the west side of the range. These structures deform Paleozoic rocks, but in this area their relation to Tertiary rocks is ambiguous. The dominant set in a younger fault system cuts the Tertiary rocks but parallels the older structures. These younger faults border the range and prominent topographic benches on both flanks. A second, northeast-trending set includes a major fault at the precipitous north end of Ward Mountain and prominent faults associated with mineralization in the Ely copper belt, at Robinson Canyon, and at the Ward Mine.

STRUCTURAL FEATURES, CENTRAL DIAMOND MOUNTAINS, NEVADA

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The Diamond Range, Eureka and White Pine counties, Nevada, is a series of north-trending asymmetric folds of Silurian through Permian beds. The area was included in a reconnaissance map published by Dott (1955) in connection with Pennsylvanian stratigraphic studies.

Detailed mapping, still in progress, shows strongly asymmetric folds overturned toward the east and modified by transverse and longitudinal faults. Extreme disharmonic folding of conglomerates and limestones is seen in some areas.

A west-dipping normal fault and a northeast-trending vertical fault outline a trapdoor block of the Ely limestone and overlying Permian sediments in the Judd canyon area. Spatial relationships of the *Chaetetes* zone in the Ely limestone, and the habit of folds in the area seem to require absolute upward movement of the trapdoor block.

An angular unconformity at the base of massive mid-Permian conglomerates, as well as other breaks in the sedimentary record, indicate deformation in the area prior to the folding of the Permian.

ENGINEERING GEOLOGY OF GLEN CANYON DAM SITE, COLORADO RIVER, ARIZONA

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Glen Canyon Dam is one of the key structures in the overall plan for the development of the Upper Colorado River Basin. The dam will be a concrete gravity arch with a crest length of 1500 feet and a height of nearly 700 feet above bedrock. This dam is being constructed in one of the more spectacular canyons cut by the Colorado River, in the nearly horizontal formations of the Colorado Plateau province.

There are a number of dam sites in Glen Canyon which could have been used for the location of a high dam. Preliminary studies of the six most favorable sections of the canyon narrowed the choice to two sites. More detailed studies, including topographic and geologic mapping, exploratory drilling, and test drifts led to the selection of the present site, 15 miles upstream from Lee Ferry, Arizona.

The foundation and both abutments consist wholly of the massive, yet highly cross-bedded Jurassic Navajo sandstone. This sandstone is made up essentially of clear quartz, minor amounts of feldspar, variably cemented with secondary quartz, minor amounts of hematite, and some chalcedony and calcite. At the dam site the formation is nearly horizontal, free from major structural defects, and characterized by widely spaced, nearly vertical joints.

Construction at the Glen Canyon Dam is proceeding ahead of schedule, and the geologic conditions and the engineering properties of the sandstone determined by the detailed pre-construction studies are being borne out by the actual findings in the excavations.

SURFACE-WATER HYDROLOGY OF ARID LANDS

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Historical reports of the Southwest picture conditions much different from those of today. In 1690 there were lush meadows and large cienegas in the basin of the Santa Cruz River. The irrigated agriculture of the valley supported several communities of about 1000 persons. During the 1880's the streams of the Southwest started cutting deep channels in widely scattered localities. Today, streams that once were perennial flow only after heavy rains. These changes in the regimen of streamflow have not been fully documented because discharge records are available for only about 50 years. Nevertheless, the changes have had profound influence upon the economy of the region, since the streams are the perennial source of water.

It is commonly believed that the surface waters of Arizona have been completely developed. Dams on the major streams impound all the surface flow that reaches the reservoir area. Of all the precipitation on Arizona more than 95 per cent is lost to evapotranspiration. The water lost from stream channels alone may equal or exceed the replenishable supply. Recovery of a large part of this loss seems feasible, but, before any large-scale operations for salvage can be successfully undertaken, more information must be obtained on the nature of the losses from the streams. The Geological Survey, in co-operation with the University of Arizona, is initiating a program of research designed to provide some of the facts required for water salvage.

ULTRASONICS—LABORATORY TOOL OR TOY?

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Ultrasonic appliances, currently manufactured by many firms, are enjoying increasing use in industry and science. These devices suggest two possibilities for geologic investigation. Immersion-type apparatus should decrease time required for disaggregation of softer sediments for sedimentation

studies or microfossil recovery and should increase the efficiency. Ultrasonic drilling tools permit more rapid cleaning and preparation of megafossils and vertebrates than currently used procedures. Preliminary experiments with both techniques and current price data are presented.

HURRICANE FAULT PROBLEM, UTAH AND ARIZONA

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The Hurricane fault is a Laramide reverse fault. Dip is steep to the east, strike-slip component is negligible. Principal manifestation of compression is the east dip, convex upward, of the strata of the western, relatively dropped block. The Kanarra fold is slightly younger than the major Hurricane (reverse) fault, not considerably older as previously thought. Total displacement on the reverse fault is probably not much more than 3000 feet, dip slip.

Structural homologues of the Hurricane fault complex are the Cedar Pocket Canyon-Shebit-Gunlock fault complexes 30 miles west of the Hurricane fault. Comparison of structures indicates penecontemporaneity of major thrusting with major reverse faulting at the close of the Cretaceous.

By analogy, probably many of the major north-northeast-trending faults of the western Colorado plateau, for example the Grand Wash, Prospect Canyon, and Toroweap faults, and of the northeastern Basin and Range are Laramide reverse faults.

Consequently, the Colorado River probably formed as a west-flowing obsequent stream; developed by pirating the south-flowing headwaters of the ancestral, southeast-flowing Rio Grande; and produced a system which incised the presently deeply buried topography of the Basin and Range, probably in the Eocene. Damming by late Eocene to early Miocene lavas impounded waters in large playas or shallow lakes which partially desiccated by evaporation. Subsequent overflow and incision probably in late Miocene produced the present drainage pattern.

DEVELOPMENT OF COLLOFORM CHALCEDONY AND QUARTZ CRYSTALS IN A SINGLE FOSSIL CORAL

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In each of two specimens of silicified coral collected at Ballast Point in Florida the hollow interior has been partitioned into two chambers, one of which is lined with colloform chalcedony and the other with quartz crystals. There is no proof that the two varieties of quartz were deposited simultaneously. The thickness of the silica deposited in one chamber is about the same as that in the other, however; the important difference is that the upper part of the silica in one chamber was deposited as chalcedony and in the other as quartz crystals. The similar total thickness and the details of the layering in the deposits suggest that the two were deposited at the same time and at about the same rate. These specimens indicate that chalcedony and quartz crystals can form under similar conditions of temperature, pressure, and concentration of silica in solution. A feature that may give a clue to why two varieties of quartz have formed under essentially the same environmental conditions is a small opening a few millimeters in diameter in the wall of the chalcedony-lined chamber. The wall of the chamber lined with quartz contains no visible openings. The opening in the wall of one chamber gave the solutions free access, and perhaps at times permitted the cavity to be drained. In the other chamber, the relative imperviousness of the wall probably allowed the chamber to remain continuously filled with silica-bearing solutions, and quartz crystals were able to grow in this aqueous medium.

TRANSVERSE STRUCTURES IN SOUTHERN ARIZONA

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The complication of Laramide fold structure in southern Arizona, as revealed on aerial photographs, may be in part the effect in cover rocks of left-lateral movement on a system of basement faults. A plot of bedding trends shows segments having a reverse S pattern. The center of the S is often northwest to north-northeast, and it passes at both ends into steeper, west-northwest bedding.

Mapping at Sawmill Canyon 35 miles southeast of Tucson disclosed at the surface what is considered to be one of the basement wrenches. This area gives some evidence for the history of Laramide deformation visualized from the bedding attitudes: (1) northwest folding; (2) reactivation of old west-northwest wrench faults, resulting in: (3) dragging and buckling of cover folds into the west-northwest trend; (4) destruction of west-northwest folds by steep bedding faults over basement wrench faults; and (5) intrusion of stocks into cover over wrenches.

QUARTZ-BEARING BASALTS OF BEAR RIDGE, MT. ABBOT QUADRANGLE, CALIFORNIA

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A series of small, thin flows of "normal" olivine basalt on Bear Ridge in the High Sierra contain locally abundant, minute, xenolithic inclusions. Similar basalts occur in adjacent quadrangles and elsewhere in the Sierra. Inclusions in the Bear Ridge flows are of four types: (1) clots of clinopyroxene; (2) granitic rock; (3) plagioclase-quartz and plagioclase; (4) corroded quartz. Fragments of quartz commonly are enclosed by reaction rims containing magnetite, plagioclase, and minerals of the diopside–augite series. Plagioclase in the xenoliths generally exhibits only moderate reaction effects; a few crystals have been entirely replaced by magnetite. No sanidine was observed, although minor amounts of potassium feldspar occur in some of the basalts.

The clinopyroxene inclusions and some of the plagioclase probably were incorporated into the basalts from a source at depth. Field and petrographic evidence indicates that the other inclusions were not derived from wall rock at great depth, nor by mixing of magmas, but have their origin in granitic debris picked up by the basalts as they flowed over the glaciated ridge. The nature of the reaction between the quartz fragments and the enclosing molten lava is discussed; it is concluded that a metasomatic type of reaction probably occurred and that simple fusion played only a minor role.

TIMING OF POST-OROGENIC UPLIFT IN THE ROCKY MOUNTAINS AND THE COLORADO PLATEAU

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There is no geomorphic evidence of early Cenozoic peneplanation of hard rocks in the eastern Cordilleran region, nor any other evidence that post-orogenic regional uplift was separated from the Laramide orogeny by an interval of crustal quiesence. Regional uplift began early in the Cenozoic and may continue today. Pliocene erosion surfaces are pediments rather than peneplanes and were formed at high altitudes. Late Cenozoic downcutting is not evidence of quickened uplift because it

may have been caused by climatic change. There is no compelling evidence that post-orogenic uplift has been pulsational.

Igneous activity, including volcanism and emplacement of hypabyssal intrusions, occurred at many widely scattered places. In some places it was late-orogenic, but in many it started after the close of the orogeny and has continued through much of the Cenozoic.

The hypothesis is advanced that the regional uplift and the igneous activity had a common cause—namely, a temperature increase at depth. The heat was principally radiogenic. Absence of igneous activity prior to the orogeny means that the region was then in a thermal steady state. The late- and post-orogenic increase in temperature was caused by orogenic thickening of radioactive sial. Because thermal expansion of rock is quantitatively inadequate to explain 5000 to 7000 feet of regional uplift, the uplift is tentatively credited in part to a change in state at depth.

This hypothesis, that Cenozoic events were controlled by a post-orogenic build-up of radiogenic heat at depth, means that "timing is the crux of the problem."

USE OF FOSSIL SILICOFLAGELLATES IN PALEOGEOGRAPHY

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Silicoflagellates are defined here as marine, planktonic Mastigophora (Protozoa) with a flagellum and a skeleton of hollow siliceous rods. These organisms also contain color-pigment organelles and therefore are treated by some authorities as plants (Algae) and by others as an animal-plant group (Protista).

This report deals primarily with the paleoclimatological aspect of paleogeography. It presents data and reasoning which led to the discovery that these microscopic animals can be used to indicate Cenozoic, but not Cretaceous, climates.

Ecologic conclusions based upon paleontological collateral evidence and studies of recent silicoflagellates indicate that the lithologic units sampled were deposited in marine waters which had the following surface or near-surface temperatures: 0°–5° C. for the Mio-Pliocene Monterey formation (type area), Monterey formation in Buttle Canyon (near Bradley), and lower part of the Sisquoc formation (Purisima Hills); 10°–15° C. for the lower part of the Mio-Pliocene Sisquoc formation (Lompoc area); 17°–20° C. for the Upper Miocene Valmonte diatomite; 25° C. for the Middle Miocene diatomite at Sharktooth Hill; and 20°–25° C. for the Upper Eocene "Sidney Flat" and Kellogg shales.

PALEOECOLOGY OF THE RAMPART CAVE GROUND SLOTH

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Fossil dung of the extinct ground sloth, *Nothrotherium shastense*, was collected by Shutler from a 5-foot section in Rampart Cave, at 1700 feet in the Lower Grand Canyon, Arizona. Carbon-14 age determination by the Lamont Geological Observatory indicates that the sloth lived in the cave until 10,000 years ago. The deepest dung level, 54 inches, was dated as older than 35,000 years, the 18-inch level at 12,000 years.

Apparently the ground sloth occupied Rampart Cave during the Late Wisconsin until the end of the late-glacial period. Pollen study of the dung reveals high percentages of sage brush (*Artemisia*) and juniper in deeper levels, with less frequent occurrences of birch (*Betula*) and pine. None of these plants occur today, or would be expected, at this elevation in the lower Sonoran zone. Above the 18-inch level there is a rise in *Ephedra* and a decline in sage brush, pine, and birch. This may represent a warmer-drier climate of the Allerd-Two Creeks age. Great variation appeared within a small num-

ber of replicate dung samples, presumably because of seasonal changes in plant-pollen production and the indiscriminate browsing habits of the sloth. For this reason climatic interpretation of a pollen diagram based on single samples at 6-inch intervals can proceed only in the most general terms.

BANERJEE'S STUDY OF THE ORACLE GRANITE

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Older Precambrian Oracle granite, named by Tolman, varies irregularly in composition but is essentially quartz monzonite. Foliation in this coarse-grained, porphyritic rock usually strikes northeastward, but exceptions are of great interest.

Locally, near the N. 70° W. trending Mogul fault, which separates granite from Pinal schist and younger rocks to the south, the granite foliation turns eastward to parallel the fault. Mogul fault moved by left-lateral strike slip, probably in "Laramide" time.

At some places in the granite a northwest-trending foliation crosses, or is crossed by, the northeasterly one, and at a few places a separate west-northwest foliation appears. There seem to be no age differences among the various foliations.

Metamorphic and metasomatic processes played some genetic part. A dike sequence seems to reveal important changes in the stress field during the structural history.

RECENT CONCEPTS OF ORE LOCALIZATION IN SOUTHERN ARIZONA

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Backed by the ideas of lineament tectonics and the localization of ore on the resulting intersections, the suggestion recently made by Schmitt can be somewhat further developed. A major intersection may have localized especially deep geosynclinal sinking and filling. In the destruction of the geosyncline, not only folding, thrusting, and intrusion, but various adjustments along the trends of lineaments, or geosutures, may have functioned.

In very few cases, where details are available, left-lateral strike slip on west-northwest shift zones is suggested. The motion seems to have been strictly localized, possibly by weakening of the basement. One known example, Silver Bell, seems to illustrate the localization of ore by such motion.

STRATIGRAPHY AND STRUCTURE OF THE CENTRAL WATERMAN MOUNTAINS, PIMA COUNTY, ARIZONA

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The Waterman Mountains, about 35 miles west of Tucson, Arizona, are composed primarily of Paleozoic rocks. Here the Paleozoic strata, characteristic of southern Arizona, are generally thinner than to the east and west.

The oldest sedimentary-rock unit is the Middle Cambrian Troy quartzite, whose contact with Precambrian(?) granite is covered except where it is exposed along faults. The Troy quartzite (220 feet thick) is overlain in succession by the Cambrian Abrigo formation (718 feet thick); the Devonian Martin formation (385 feet thick); the Mississippian Escabrosa limestone (228 feet thick); the Pennsylvanian Horquilla formation (488 feet thick); the Pennsylvanian and Permian Andrada formation

of Turmond, Heinrichs, and Spaulding (1,100 feet thick); and the Permian Scherrer formation (422 feet thick), Concha limestone (510 feet thick), and Rainvalley formation of Bryant (321 feet thick). Most of the Paleozoic units are conformable; a few are separated by minor erosional unconformities.

The Paleozoic rocks form the highest parts of the range; the lower slopes and adjacent lowlands are underlain by Cretaceous(?) shale and arkosic sandstone, mostly covered by alluvium.

The principal structure is an intricately faulted northwest-trending, southeast-plunging recumbent fold. The steep flank is to the northeast and is moderately well preserved. The southwestern flank has been broken by imbricate thrust and associated normal faults, and a part of the southwestern flank is presumed to have been offset to the east along a strike-slip fault.

INVERTEBRATE FAUNA OF THE NIOBRARA FORMATION (CRETACEOUS) OF KANSAS

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Twenty-two of the 43 species previously reported or described from the Niobrara formation of Kansas are retained as valid. The remaining species are either placed in synonomy or referred to *nomena dubia*. Seven species previously unknown in the Niobrara formation of Kansas are recorded.

Inoceramus grandis Conrad is redefined to include *I. niobrarensis*, *I. eccentrica*, and possibly *I. concentricus*. The large, thin-shelled, flat inoceramid is identified as *Inoceramus platinus* Logan. The genus *Pseudoperna* Logan is synonomized with *Ostrea* Linne. *Radiolites maximus* Logan is referred to the genus *Durania*. The presence of *Bevahites*, a texanitid, two species of *Baculites*, including *Baculites* cf. *B. codyensis*, and *Clioscaphites vermiformis* are recorded. A new type of aptychus is described and recorded. The genus *Platylithophycus* Johnson and Howell, a supposed alga, is referred to the sepioid cephalopods.

The environment of deposition is interpreted as a relatively calm, density-stratified, epeiric sea, in which the near-bottom waters became stagnant and foul, thus limiting the abundance and variety of benthonic life. The sediments were colored gray by the accumulation of organic matter. The gray color is lost during weathering, and the sediments become stained bright colors by the oxidation of iron sulfides contained in the chalk.

SODIC AMPHIBOLES AND METAMORPHIC FACIES IN MOUNT SHUKSAN BELT, NORTHERN CASCADES, WASHINGTON

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West of the metamorphic core of the Northern Cascades extends a belt of partly Na-amphibole-bearing, basalt-derived schists. The author has studied the northern part of the belt.

Intricately zoned Na-amphiboles display the following isomorphous series: 1. Highly ferric crossite—less ferric crossite—uniaxial member—ferric glaucophane; 2. last three form isomorphous series with actinolite: parallel-symmetric sodic actinolites; 3. intermediate crossites mixed with actinolite form normal-symmetric "crossactinolites"; between ferric crossites and actinolite exists miscibility gap. Zoning normally is from more to less ferric, and to increasingly actinolitic. "Reversely" zoned cores record early metamorphic stage.

Tremolite-actinolite greenschists (= a) predominate. In intercalated blue amphibole schists (= b) crossite exceeds glaucophane. The (a) and (b) share epidote, albite, and relatively subordinate chlorite. As Na-amphibole increases, albite decreases. Na varies within same normal-basaltic range in (a) and (b). Fe''': Al is consistently higher in (b). Formation of Na-amphibole depends not on high Na but on Fe'''.

In this "crossite subfacies" only more ferric Na-amphiboles are stable. Tremolite-actinolite does

not react with albite to form nonferric glaucophane. Even ferric glaucophane is generally confined to early and late stage, except on the south. This transition to "ferric glaucophane subfacies" becomes obvious farther south where J. A. Vance found crossite and glaucophane about equal, and significant Na-pyroxene, lawsonite, and pumpellyite, although epidote remains dominant, and tremolite-actinolite greenschists still predominate. Reaction between tremolite-actinolite and albite defines the third subfacies, not developed in the Cascades.

This subfacies sequence reflects increasing *P* within chlorite-zone *T* interval. Within this interval and at constant *P*, lower *T* would permit less ferric Na-amphibole. Zoned Na-amphiboles are attributed to earlier rise and later drop of *T*. The consistent relationships found hardly reflect only variable P_{H_2O}.

At lower-*P* end of sequence belong actinolitic greenschists without crossite rocks. Such occur east of Shuksan belt and apparently reflect eastward rising isotherms, toward Skagit gneiss, near which the grade increases to oligoclase-epidote and andesine-epidote amphibolites.

AGE OF THE CARLSBAD CAVERNS AND RELATED CAVES IN ROCKS OF GUADALUPE AGE WEST OF THE PECOS RIVER IN SOUTHEASTERN NEW MEXICO

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From a plateau bounded by a 500-foot escarpment, Carlsbad Caverns extend 1000 feet in the Capitan limestone to more than 470 feet below the level of the escarpment's base. Because the caverns extend far below present surface drainage, some geomorphologists have maintained that they were formed by water moving eastward into the Delaware basin prior to the present erosion cycle. New information, however, shows that meteoric water is still dissolving limestone below the lowest present cave level and is moving northward along the Capitan reef to discharge into the Pecos River. Siliceous gravel deposited atop the escarpment in Ogallala time or early in the history of the Pecos River indicates that major uplift of the Guadalupe Mountains and solution of deeper caves began after the gravel was deposited.

In post-Capitan, pre-Ogallala time the original porosity of the Capitan limestone may have been increased by movement of interstitial water; however, seemingly only the upper cavern levels formed by meteoric-water solution. The Guadalupe upland was near base level, as indicated by lack of truncation of carbonate rocks on the shelf, the stripped-plain aspect of the upland, and the small amount of solution in the dolomites of the shelf area.

With post-Ogallala uplift, the Pecos River breached the Capitan limestone, highly mineralized water drained out, and meteoric water gained access to lower levels in the limestone. Caverns were formed at successively lower levels as base level and the water table were lowered.

AREAL GEOLOGY ALONG NORTHEAST SIDE OF SAN ANDREAS FAULT, LITTLE SAN BERNARDINO TO OROCOPIA MOUNTAINS, CALIFORNIA

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Areal geology of 864 square miles was mapped at 1:24,000 as part of the current geological exploration program of the Southern Pacific Company. Included are portions of San Bernardino, San Jacinto, Little San Bernardino, Hexie, Pinto, Cottonwood, and Orocopia mountains, and parts of Indio and Mecca hills.

Southwest faces of these mountains form a major northwest-trending scarp separating the uplifted Mojave Desert block on the northeast from the depressed Coachella Valley portion of Colorado Desert on the southwest. The northwest-striking San Andreas fault occurs along the southwest side of Mecca and Indio hills, the fault-slice ridges at the foot of the major scarp.

Within a 10-mile-wide zone along the major scarp, several important faults are subparallel to the San Andreas. The Mojave Desert block has been elevated along these faults. A major east-trending fault cuts Little San Bernardino Mountains, and left-lateral movement offsets Hexie Mountains about 4 miles. A tectonic cycle of compression–tension–lateral slip is indicated to have occurred during Quaternary time.

Two pre-Cretaceous metamorphic units are well exposed in the mountains: Chuckwalla metamorphic complex, consisting of crenulated meta-igneous and metasedimentary gneiss and schist; and apparently younger Pinto gneiss, largely planar-schistose, metasedimentary biotite-quartz gneiss. Chuckwalla and Pinto are further distinguished by local marble and metasyngenetic(?) magnetite in the former and quartzite beds in the latter.

Separating Chuckwalla from Pinto are extensive bodies of Cactus and White Tank quartz monzonite and tonalite, possibly part of southern California batholith of Cretaceous age.

Mineral deposits include high-grade fluorite veins, titaniferous magnetite, and copper-gold-quartz veins.

SURFACE-WAVE DISPERSION FOR OCEANIC PATHS

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When the path between the epicenter and the station traverses deep oceanic basins primarily, the surface-wave trains from shallow shocks recorded by ordinary long-period seismographs may be separated into two classes on the basis of wave periods. The first class consists of Love and Rayleigh waves with periods greater than about 15 seconds. The second class includes waves with periods between about 20 and 5 seconds.

Numerical computation of surface-wave dispersion for theoretical models of structures which differ only slightly from those described earlier can account for some previously unexplained features of these wave trains. For example, the effect of low rigidity in the sedimentary layer distorts the dispersion curves sufficiently to account for the long duration of the short-period Love-wave train. The curve for the fundamental Rayleigh mode is also distorted in the range of periods which is unaccountably absent on seismograms.

LATE PLEISTOCENE MARINE TERRACES ON SANTA ROSA ISLAND, CALIFORNIA

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A 25- and 75-foot wave-cut platform is capped with both Pleistocene marine and terrestrial fossiliferous deposits. The lower (25-foot) platform is overlain by marine and terrestrial deposits containing dwarf mammoth bones. Over this the upper (75-foot) wave-cut platform is cut into both the lower (Pleistocene) clays and (Miocene) shales and is capped by a shallow marine deposit, followed by terrestrial calcareous sands, clays, and eolianite. These sands, dated by radiocarbon, have an age in excess of present radiocarbon limits. The upper member lies unconformably upon these beds and consists of clays with lenses of fire-reddened earth, charcoal, and burned mammoth bone radiocarbon dated from 12,500 to 29,750 years BP.

The 25-foot platform is found world wide; the equivalent of the 75-foot platform is found on the Santa Barbara mainland, San Clemente Island, North Pacific Islands, Australia, and the Mediterranean.

The upper half of the fire-reddened member ranges in radiocarbon age from 12,500 to 30,000 years; by extrapolation a conservative age of 50,000 to 60,000 years may be assumed for the lower portion. The underlying intermediate member has been dated at more than 33,000 years B.P. The

presence of widespread calcareous sands and eolianite suggests a Third Interglacial age for the underlying intermediate member.

DAVIDITE FROM THE QUIJOTOA MOUNTAINS, PIMA COUNTY, ARIZONA

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Davidite occurs in a transitional contact zone up to 10 feet wide between a metaspessartite dike and quartz monzonite on the west side of the Quijotoa Mountains, about 5 miles west of Covered Wells, Pima County, Arizona.

The contact zone is composed of albite, epidote, chlorite, quartz, sphene, and calcite with minor apatite, specularite, and allanite. Davidite as pitchy, black grains up to half an inch across is concentrated within this zone along the metaspessartite contact in irregular clusters with lenses of epidote and sphene. Rutile, sphene, and "leucoxene" occur as alteration products of the davidite.

X-ray examination of davidite showed it to be nearly or wholly metamict. Fragments heated to 900° C. in air turned to single crystals with small weight loss and no marked change in density or color. Heating to 1375° C. causes no further change. Density of unheated davidite was 4.42. Reconstituted crystals were studied by Weissenberg and precession patterns. The space group is $R\bar{3}$ or R3, cell dimensions (hexagonal) a_0 10.36Å, c_0 20.85. The powder pattern of davidite from Mozambique, published by Kerr and Kulp, can be fully indexed on this cell as can the powder pattern of type davidite, judging from the schematic representation by Bannister and Horne. Davidites from Radium Hill, Billeroo and Thackeringa, Australia, and from Mozambique were examined for comparison. None of these could be reconstituted to single crystals, but powder patterns of all conform to the lattice found from the Arizona davidite.

TECTONIC RECORD OF THE STILLWATER RANGE, WESTERN NEVADA

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That part of the Stillwater Range which lies within Churchill County, Nevada, was studied with regard to structural development. The range is largely a north-northeast-trending horst with simple outlines which belie a complex history.

The Late Jurassic and (or) Cretaceous orogeny of western Nevada is recorded by folding and local overturning of Upper Triassic slate and probably Lower Jurassic strata in a manner suggesting north-northeast relative movement of the upper portion with respect to deeper parts. The entire body of Mesozoic rock may be allochthonous, as the lower boundary is a thrust fault in the only known exposure. Several klippen of limestone and Havallah quartzite (Permian?) rest upon the Upper Triassic slate.

Early Tertiary or Late Cretaceous andesitic rocks and devitrified acidic welded tuffs lie unconformably upon the older formations and are intruded by stocks of diorite, white felsite, andesite porphyry, quartz monzonite, and granite.

Subsequent Tertiary rocks include acidic tuffs and thin Pliocene(?) nonmarine sediments. These were moderately folded along north-south and northeast-southwest axes in the Late Pliocene. Early Pleistocene(?) olivine basalt forms an unconformable capping.

Quaternary deformation included very gentle folding or tilting and the development of many north- to northeast-trending normal faults. A few of the latter became the principal faults delimiting the range. The latest tectonic episode was normal fault displacement (up to 7 feet) in December 1954, along some of the marginal faults. Strike-slip faulting did not occur along the Stillwater Range, although it is well documented farther south near Fairview Peak.

STRUCTURAL GEOMETRY OF PRE-GRANITIC ROCKS IN THE SIERRA NEVADA, ALPINE COUNTY, CALIFORNIA

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Detailed mapping of three roof pendants in western Alpine County, California, disclosed a complex structural geometry in pre-granitic metamorphic rocks. At least two episodes of deformation of these rocks are inferred from geometrical studies.

Major structures are northwest-plunging isoclinal folds of the bedding with steeply southwest-dipping axial planes. Steep superposed folds of bedding and mineral lineations are present on the flanks of the major structures. Folds of a subvertical metamorphic surface are coaxial with the major bedding folds in some areas and are coaxial with the steep superposed structures in other areas.

Early deformation by flexural slip on bedding was followed by flow of the already folded rocks parallel to the metamorphic surface. Nonrotational displacement along two basin-and-range faults is indicated by homogeneity of fabrics of the roof pendants.

ORIGIN OF THE DACITE NEAR SUPERIOR AND GLOBE, ARIZONA

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A large sheet of Tertiary(?) dacite in the vicinity of Superior and Globe, Arizona, covers at least 400 square miles, is locally as much as 1500 feet thick, and has been interpreted in the past as a lava flow. Recent recognition of many silicic volcanic rocks as welded tuffs has cast doubt on the lava-flow interpretation. However, certain widely accepted criteria for the recognition of welded tuffs are lacking. The nearly uniform specific gravity in the main part of the unit, the absence of deformed glass shards, and the presence of locally continuous flow structures seem inconsistent with interpretation as a welded tuff.

The following evidence explains these objections and supports a pyroclastic origin: (1) the wide areal extent and the uniformly flat or low-dipping planar structures of this dacite are not characteristic of silicic lava flows; (2) pumice blocks, equidimensional near the top, become successively more flattened downward in the unit and are absent in the lower part; (3) relict outlines of lapilli can be distinguished in some specimens; (4) structures previously interpreted as flow structures are actually the deformed borders of lapilli and pumice blocks; (5) many phenocrysts are broken; (6) small lithic inclusions are distributed fairly uniformly through the dacite. If glass shards were ever present, they have been obliterated by devitrification. The progressive downward flattening of pumice blocks and accompanying changes in matrix lithology suggest that the dacite was deposited by a single huge pyroclastic eruption.

NEW RESULTS ON MANTLE AND CRUSTAL STRUCTURE

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Crustal structure in the vicinity of the California–Nevada border is being studied by three separate methods—surface-wave phase velocity, gravity, and explosion seismology. The first two methods indicate a crustal thickness of about 40 km. Explosion-seismology results are concordant only if an intermediate crustal layer is present. Explosion data for the existence of this layer are discussed, and it is shown how without sufficient detail this layer can be overlooked and erroneous conclusions reached.

A study of *G* waves for purely continental paths indicates that the corresponding velocities are identical or differ by no more than about 2 per cent. This implies that the low-velocity zone in the mantle is identical under continents and oceans and suggests that the pressure, temperature, and composition are also similar.

EXTENT OF THE ANTARCTIC CONTINENT

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Records from the Press-Ewing seismographs of the Wilkes Station in Antarctica were analyzed for Rayleigh-wave and Love-wave dispersion. When corrected for non-Antarctic path segments, Antarctic-group velocities were abnormally high compared to data from other continents. These results indicate that at most only three-fourths of the Antarctic ice sheet is underlain by continent; the remaining area is oceanic in structure.

AREAL GEOLOGY OF A PORTION OF THE LITTLE SAN BERNARDINO MOUNTAINS, RIVERSIDE AND SAN BERNARDINO COUNTIES, CALIFORNIA

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The areal geology of much of the Little San Bernardino Mountains was mapped (scale 1/24,000) as part of the current geological exploration program of the Southern Pacific Company.

The Little San Bernardino Mountains, a northwest-trending range, lie entirely within the Mojave structural block. The range forms a major portion of the southern limits of this geomorphic-geologic province. Major faults delineate the range from adjacent physiographic features—*i.e.*, the San Bernardino Mountains on the northwest, the Hexie and Cottonwood mountains on the southeast, and the Indio Hills on the southwest. Vertical movement faults are more numerous than those of lateral movement and include: Morongo Pass, Pinto Mountain, and Baseline faults in the Morongo Valley area to the northwest and the Dillon, Inspiration, and North Indio faults on the southwest. A lateral-movement group is primarily represented by the left-lateral Blue Cut fault which traverses the range in an east–west direction. Indications of slight lateral adjustments are evident along faults of the Morongo Valley group.

The oldest rocks exposed are pre-Cretaceous Chuckwalla migmatitic complex and Pinto gneiss, separated by Jura-Cretaceous(?) White Tank batholithic rocks. Stratigraphic and structural relationships indicate that the Pinto gneiss is considerably younger than the Chuckwalla. Chuckwalla is extensively exposed throughout the deeply dissected southwestern flanks of the mountains, whereas the Pinto forms isolated outcrops on the northeast slopes, occurring as irregularly shaped roof pendants in White Tank.

The youngest rocks exposed include Quaternary basalt and Pleistocene fanglomerates.

INSOLUBLE RESIDUE AND POROSITY ZONES, UPPER ORDOVICIAN AND SILURIAN OF NORTHEASTERN WILLISTON BASIN

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Sampling of this predominately carbonate section was from outcrops in Manitoba and wells in the Williston Basin. The Red River yields various chert types and clastics in its lower part; upward it becomes less limy, less cherty, and more dolomitic. Detrital grains increase downward, southward, and eastward. Crystalline types are more common northward, quartzitic types southward.

Repeated Stony Mountain residues are characterized as (1) abundant silt, sand, and varicolored shale-mud; (2) chert, microfossils less silicified than Interlake fossils, evaporite salts and salt casts; (3) crystalline dolomite. Lithologically these zones are difficult to trace in the subsurface; petrographic and residue correlation appears possible.

The Interlake group shows similar residues; clastics are common near the base, yielding distinctive zones; fewer occur in the middle, but they increase near top. Siliceous replacement of carbonate, dolomite rhombs, and microfossils is common. Staining and peel techniques were especially effective in reef zones.

Red River porosity was revealed best by polished sections and was (1) primary, (2) solution, (3) fracture types; Interlake porosity was studied best by impregnation and core casts. It was primarily (1) organic, (2) solution and crystallization types.

Paleogeography indicates low-lying distant lands composed of quartzites, gneiss and schist, granites, and sandstones. Quartzite terrains were to the south and subject to wind(?) abrasion. Deposition was on a shallow shelf with occasional local semirestricted circulation and intervals of slight emergence or shoaling between Red River and Interlake times.

STRATIGRAPHIC HISTORY OF SOUTHEASTERN ARIZONA AND ADJACENT AREAS

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Thick sequences of older Precambrian sedimentary and volcanic rocks were highly deformed, intruded, and metamorphosed during the Mazatzal revolution. Younger Precambrian clastic rocks and carbonates with some interbedded tuffs and volcanic rocks accumulated on a peneplaned surface cut on older Precambrian rocks. Although locally intruded, these younger rocks are not appreciably metamorphosed.

No major deformation separated the younger Precambrian from the Paleozoic which opened with a low-lying, emergent Arizona. The western Cordilleran geosyncline and a Paleozoic embayment in southeastern Arizona and southwestern New Mexico controlled the Paleozoic seas which frequently spread across the adjacent shelves. The Defiance-Zuni positive areas, and landmasses of varying extent and persistence in central and southwestern Arizona controlled seas and sediments in those directions. Paleozoic sedimentation is characterized by carbonates, although some clastic rocks are found as shore lines are approached. Clastic rocks became more common as the Paleozoic drew to a close.

Triassic and Jurassic sediments are unreported from southern Arizona but, where present in adjacent Sonora, are predominantly marine and nonmarine clastics. This contrasts with Precambrian and Paleozoic carbonate deposits; their freedom from volcanic rocks also contrasts with volcanic-rich Cretaceous–Tertiary deposits of southern Arizona.

Southeastern Arizona Lower Cretaceous marine deposits grade westward into continental clastics locally interbedded with lavas and tuffs. Predominantly continental clastic and volcanic accumulation continued through late Cretaceous and Tertiary times. Cretaceous–Tertiary folding, intrusion, and faulting resulted in the formation of contemporaneous local basinal deposits of Cenozoic age.

MODE OF EMPLACEMENT OF THE TWIN SISTERS DUNITE, WASHINGTON

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The Twin Sisters dunite is the largest of three dunite bodies located along a major N. 40° W. high-angle fault in the Northern Cascades, Washington. The elliptical body (36 sq. mi.) intrudes phyllite and also upper Paleozoic and lower Tertiary sedimentary rocks. Intrusion has had no observable structural or contact-metamorphic effect on the surrounding country rock.

Superimposed on the coarse, inequigranular primary texture are cataclastic textures produced by granulation and mylonitization. Olivine grains have undulatory extinction, abundant translation

glide lamellae, and fractures; enstatite shows strong bending. Recrystallization of some cataclastic areas is shown by (1) glide lamellae with secondary sutured boundaries, (2) fine-grained unstrained mosaics along fractures in single grains and along lamellae boundaries, and (3) fine unstrained mosaic textures surrounding and embaying large strained relict olivine grains. Partly, purely cataclastic textures are superimposed on these by continued deformation.

A narrow, gradational, serpentinized margin, schistose at the contacts, contains exotic blocks of strongly cataclastic pyroxenites and gneissose granitic rocks.

Movement of the solid, dry dunite mass upward was accomplished by internal deformation and by marginal faulting. Cataclastic textures of early internal deformation were recrystallized at depth under conditions of high temperature and pressure. At higher levels in the crust internal movement continued without recrystallization. With reduced temperature and the formation of serpentinite, movement was largely confined to the margin of the body.

CURRENT STUDIES OF MINOR EARTHQUAKES

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A program of revision of epicenters and travel times for minor earthquakes is under way. This includes restudy of numerous shocks in the Kern County area since 1952, and of shocks in other parts of Southern California favorably located near the active stations. Particular attention is being given to: (1) a group of earthquakes in Imperial Valley on October 15, 1958, one of which was registered at several temporary stations set up for recording bomb tests; (2) a swarm just south of the International Boundary on November 30, 1958, and following days, well recorded at El Centro and distant stations; (3) a series in southern Owens Valley beginning January 5, 1959, and a short distance from Haiwee and from China Lake, showing clear phases between the principal *P* and *S* waves.

PRECAMBRIAN, CAMBRIAN, ORDOVICIAN, AND SILURIAN SPONGES IN NORTH AMERICA

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A single species of sponge has been described from the Precambrian of North America. At present, slightly more than 250 valid species of sponges have been described from the Lower Paleozoic rocks of North America, exclusive of the archaeocyathids. Approximately 50 species have been described from the Cambrian, 160 species from the Ordovician, and 40 species from the Silurian. These represent 24 genera in the Cambrian, 67 in the Ordovician, and 29 in the Silurian.

Most prolific faunas described thus far are: Burgess shale member of the Stephans formation of British Columbia; Utica and Lorraine shales and Chazy limestone of New York State; Levis(?) shale at Metis, Quebec; Platteville group of Illinois; Pogonip group of Nevada and Utah; and the Brownsport formation of Tennessee, Kentucky, and Ohio. Scattered descriptions have been made of specimens collected in nearly every major Lower Paleozoic outcrop area in North America.

Most of the faunas appear distinctly provincial, and, locally, certain of the species appear to be useful stratigraphic markers. Others, such as some species of *Receptaculites* and *Hindia*, are widespread and relatively long lived.

SEISMIC EFFECTS FROM UNDERGROUND NUCLEAR EXPLOSIONS

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Seismic waves from recent undergound nuclear explosions in Nevada were observed at a number of temporary stations along a line extending eastward to Maine. Travel times and amplitudes of *P* and *S* waves are discussed.

CENOZOIC STRATIGRAPHY OF THE VIRGINIA RANGE NEAR WADSWORTH, NEVADA*

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A thick sequence of Cenozoic volcanic rocks covers most of the southern half of the Wadsworth and northern half of the Churchill Butte quadrangles. The volcanic rocks are mainly lava flows and flow breccias with rhyolitic pyroclastic rocks and volcanic sediments. The stratigraphic sequence is similar to that in the adjacent Virginia City quadrangle but differs in having a thick basaltic unit (Chloropagus formation) between the Alta formation and the Mio-Pliocene "andesites".

	Formation	*Lithology*	*Approx. max. thickness (ft.)*
Pleistocene	Lahontan	Lacustrine sediments	75
	McClellan Peak	Alkali olivine basalt	25
	Mustang	Hornblende andesite	350
		Unconformity	
Pliocene	Lousetown	Basalt and pyroxene andesites	350
		Unconformity	
	Coal Valley	Volcanic and diatomaceous sediments	500
	Kate Peak	Rhyodacites, dacites, and interbedded sediments	1500
		Unconformity	
Mio-Pliocene	Unnamed	Upper: volcanic and diatomaceous sediments Lower: dacites and rhyodacites	1200
		Unconformity	
	Chloropagus	Basalts and andesites with interbedded tuffs and sediments	2500
		Unconformity	
Oligocene	Alta	Upper: tuffs and tuffaceous sediments (Sutro member) Lower: andesites and dacites	1600
Eocene?	Hartford Hill	Rhyolitic tuffs	2500
		Unconformity	
Paleocene?	Unnamed	Olive-green claystone	300
		Unconformity	
Mesozoic		Slate, metavolcanic rocks, granodiorite, etc.	?

The pre-Kate Peak rocks are folded about east-northeast axes and dislocated by north-south and east-northeast faults. The Kate Peak formation appears to be gently deformed along the same trend, but the Lousetown and younger formations apparently have not been folded.

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Several important unconformities are present in this section; however, the major Cenozoic hiatus is the unconformity between the Oligocene Alta formation and the Mio-Pliocene Chloropagus formation.

CALIFORNIA UPPER CRETACEOUS CONGLOMERATES AND THE LATERAL DISPLACEMENT ON THE SAN ANDREAS FAULT NORTH OF SAN FRANCISCO

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Upper Cretaceous conglomerates are common in the California Coast Ranges and are well exposed along the west side of the Great Valley. They are typically polymictic with granitic, volcanic, and quartzitic rocks constituting about three-fourths of the coarse detritus. In the conglomerates of the eastern Coast Ranges phenoclasts of basic volcanic rocks equal or exceed those of siliceous volcanic rocks. Granitic phenoclasts are common but are mainly granodiorite and adamellite with minor aplite and pegmatite. In the conglomerates of the central and western Coast Ranges siliceous volcanic phenoclasts predominate over basic; but granitic rocks are apparently of minor importance except in the late Cretaceous conglomerates.

North of San Francisco, Cretaceous conglomerates occur east and west of the San Andreas fault. Lower upper Cretaceous conglomerates near Novato and Healdsburg contain few granitic phenoclasts, and these are mainly granite porphyry. In upper Cretaceous conglomerates near Jenner and Petaluma about one-fifth to one-third of the phenoclasts are granitic rocks, and nearly half of these are aplitic and microgranitic. West of the San Andreas fault similar late Cretaceous conglomerates are present in the lower part of the Gualalla series near Stewarts Point. These conglomerates contain abundant granitic phenoclasts, but approximately half of them are aplitic and microgranitic.

These relationships and other Cretaceous lithofacies data suggest that north of San Francisco the post-Cretaceous cumulative right-lateral displacement on the San Andreas fault is considerably less than 100 miles and possibly no more than 25 miles.

GEOCHRONOLOGY OF THE SAN FRANCISCO MOUNTAIN VOLCANIC FIELD, ARIZONA

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The 100 cubic miles of lavas in the southwest corner of the Colorado plateau were studied in 1958, and it was found that the age concept as established by H. H. Robinson (1912) should be reinvestigated.

The Black Point lava flow of Robinson's first general period of volcanism covers part of the Black Point pediment, which is younger than the middle Pliocene Bidahochi surface (O. E. Childs, 1948). Yet there is no way so far to correlate any of the other first-period lavas in the very extensive field with the Black Point flow, and therefore there is no reason to believe that other first-period lavas could not be older than middle Pliocene. Furthermore, other evidence (paleomagnetism, state of erosion) indicates that the lavas of the first general period of activity are of significantly different ages, as should be expected.

The second general period of intermediate lavas does not generally show a clear relationship to older and younger lavas. Some seem to be quite young, others penetrate basaltic lava beds, and others could well be older than most other San Franciscan volcanic rocks.

The third general period reached into historical time. The youngest eruption at Sunset Crater was dated by tree-ring studies (Smiley, 1955) as 1064 A.D. Yet the stage III lavas (Colton's classification) are not necessarily younger than early Wisconsin (R. P. Sharp, 1942), since they do not overlie glacial till but rest on ash beds which could not be penetrated by test pits.

Samples have been taken and minerals for geochemical dating have been separated, and further study is anticipated.

UPPER CRETACEOUS FAUNAL ASSEMBLAGES FROM CHICO CREEK, BUTTE COUNTY, CALIFORNIA

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Three distinct faunal assemblages, divisions of the *Glycymeris veatchii* fauna, are recognized in a section of clastic Cretaceous sediments, approximately 4000 feet thick, exposed in the canyon of Chico Creek, Butte County, California. (1) The oldest assemblage, characterized by *Cymbophora* aff. *stantoni* (Arnold), *Plectocion curvirostris* (Gabb), and *Baculites* n. sp., occurs in sandstones interlensing with conglomerates of the lenticular, 700-foot thick basal unit. Matsumoto suggests Late Coniacian (?) age for this assemblage which also occurs in Popenoe's Member V at Redding. (2) The medial assemblage, collected from 1000 feet of coarse- to fine-grained sandstones with pebble and grit beds, is characterized by *Calva taffi* (Anderson), *Biplica heteroplicata* Popenoe, and *Baculites capensis* Woods. Matsumoto considers the ammonites to be of Santonian age. (3) The youngest assemblage, occurring throughout the fine-grained, massive sandstones of the upper 2000+ feet, is the *Turritella chicoensis* (s.s.) division. *Cymbophora* n. sp., *Biplica obliqua* (Gabb), and *Canadoceras* spp. are characteristic species. Ammonites identified by Matsumoto indicate Early to Middle Campanian age. Similar assemblages are found at Tuscan Springs, Butte Creek, and Pentz of the eastern Sacramento Valley, in the upper part of the Holz shale member of the Santa Ana Mountains, and in the Cedar District formation of Sucia Island.

The decrease in clast size upsection and distribution of some genera suggest changes in site of deposition from inner sublittoral for the oldest and medial assemblages to outer sublittoral for the *Turritella chicoensis* (s.s.) division.

NORTH AMERICAN LAND-MAMMAL "AGES"

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Names such as Barstovian and Hemphillian represent land-mammal "ages". These "ages", although with gradational boundaries, are successive chapters in the nonmarine history of North America. They are based upon composite aggregates of fossils of land mammals. Each aggregate is peculiar to North America. It may have been obtained from widely scattered localities. The animals represented are believed to have lived during the same restricted geochronological interval, especially when there is a high percentage of identity of species and genera throughout the geographic range of samples that make up the aggregate. This belief is made probable by the fast rates of (1) morphologic change, (2) origination and extinction of taxa, and (3) geographic dispersal of mammals.

Mammal "ages" may have duration comparable to the ages of modern stratigraphic practice but lack a myriad of data that should be employed in the definition and characterization of a stage-age. Some mammal "ages" appear to overlap the epoch boundaries that are currently recognized in Europe. Attempted boundary adjustments of such "ages" have led to futile controversy, because the antagonists in the controversy do not realize that the criteria with which they work are peculiarly North American. European workers are developing precise stratigraphic correlations between the land-mammal faunas and the marine biostratigraphic units in the type areas of the stages and series on their continent. These correlations will provide us with the critical data for better comparison of North American land-mammal "ages" and the European "standard".

STRESSES IN THE EARTH'S CRUST

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(On leave from Imperial Oil Co., Canada)

Earthquakes are commonly thought of as the expression of a fracture or slip phenomenon occurring in the Earth's crust. This slip phenomenon is the result of the prevailing stresses reaching a point at

which static equilibrium is no longer possible. It has now become possible to determine the regional stresses in the Earth's crust directly in the vicinity of a well. This is accomplished by an analysis of hydraulic fracturing data. The theory underlying this method is based upon the assumption that the inducement of fracturing in a well occurs through failure of the material under a tensile stress. Values of the regional stresses are calculated for five wells for which bottom-hole pressure charts during a fracturing operation have been available. The stress differences found are of the order of up to 2000 lbs/sq. inch. In all cases, the stress state corresponds geologically to incipient transcurrent (wrench) faulting. While no unwarranted conclusions should be drawn from results from only five wells, it may nevertheless be noteworthy that the stress state found is in agreement with the transcurrent faulting postulated by most fault-plane solutions of earthquakes.

UNUSUAL COMPOSITION OF WATER FROM AQUA DE NEY, SISKIYOU COUNTY, CALIFORNIA

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The unusual, perhaps unique, chemical character of water from Aqua de Ney, a cold (54° F.) spring discharging about a gallon per minute, was reported by G. A. Waring in 1915. The water has been re-analyzed in greater detail as a facet of a research project involving identification of water sources by means of chemical analyses.

Aqua de Ney yields the most concentrated water of any of a group of springs situated in a canyon about 5 miles southwest of Mount Shasta City, Siskiyou County, California. Rocks exposed include quartz keratophyre, which composes the south wall of the canyon, and basalt and andesite, which compose the north wall. The contact between the rocks on either side of the canyon is concealed and may be either depositional or fault. The rocks are partly serpentinized, and one small outcrop may represent older schistose greenstone.

Its redox potential (−.22) indicates that the water comes from a strongly reducing environment. The pH of the water is 11.6, and its specific conductance is 36,800 micromhos. The concentration of dissolved solids is 31,200 ppm and of silica 4000 ppm, the greatest silica concentration in a natural water known to the writers. The water contains also the following ions:

	Ppm		*Ppm*
Al	1.8	OH	1,430
Fe	.00	CO_3	5,560
Mn	.00	HCO_3	0
As	.00	SO_3	295
Ca	7.3	SO_4	267
Mg	2.6	Cl	7,180
Na	10,900	F	3.0
K	135	Br	11
Li	3.2	I	5.7
NH_4	148	NO_2	100
B	242	NO_3	0
		PO_4	4.3
		Sulfide as H_2S	1,000

Titration of the water with sulfuric acid produced a titration curve having inflection points notably different from those characteristic of the carbonate-bicarbonate-hydroxide titration curve. Undoubtedly the quantities of silicate, borate, and perhaps of ammonium caused these differences.

LIMITATION IN THE DEVELOPMENT OF GROUND-WATER RESERVOIRS IN THE SOUTHWEST

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The ground-water reservoirs of the Southwest are in general found in the deep alluvial-filled valleys in the Basin and Range province of western United States. Their great depth and areal extent permit the accumulation of vast quantities of ground water. Over the period of hundreds and even thousands of years the water table, prior to extensive development by pumping, had reached a position of approximate equilibrium. Variation in recharge between wet and dry periods had little significant effect upon the total amount of water in storage. Natural discharge by native vegetation and evaporation from shallow-water areas, plus surface flow and underflow leaving a ground-water basin were thus a measure of the average recharge to a ground-water reservoir. A ground-water inventory evaluating these factors as they were before excessive pumping began thus provides at least one method of estimating the safe yield of a ground-water reservoir.

Under constantly changing water-table conditions in areas of rapid ground-water development the problem of determining safe yield becomes more involved. Lowering of the water table with probable wide variations in specific yield or storage coefficient together with the necessity for knowledge of artificial discharge from pumping plants become important factors. Natural recharge is in general increased and natural discharge decreased with the quantitative amounts of each required in evaluating the safe yield.

STRUCTURE AND QUATERNARY STRATIGRAPHY OF METEOR CRATER, ARIZONA IN THE LIGHT OF SHOCK-WAVE MECHANICS

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Meteor Crater is a bowl-shaped depression encompassed by a ridge or rim that rises 100–200 feet above the surrounding plain. The rim is underlain by a complex sequence of Quaternary debris resting on older disturbed strata. Three units of rock debris have been mapped in the rim in ascending order: a unit of red sandstone and siltstone fragments from the Moenkopi formation (Triassic), a unit of dolomite fragments derived from the Kaibab limestone (Permian), and a unit composed of sandstone fragments from the Coconino sandstone and Toroweap formation (Permian). The bedrock stratigraphy is preserved, inverted, in the debris. Alluvial and colluvial deposits, correlative in part with Pleistocene and Recent formations in the near-by Hopi Buttes region, rest with pronounced unconformity on the debris.

Permian and Triassic strata in the crater wall dip moderately to steeply outward from the crater and are overturned near the contact with the debris of the rim around one-third of the crater wall. Locally the Moenkopi formation is folded back on itself, and the upper limb of the fold consists of a flap that has been rotated, in places through more than 180°, away from the crater. At one place the flap grades outward into disaggregated debris.

These features of Meteor Crater correspond closely to those of an atom-bomb crater in which depth of burial of the device was about one-fifth the diameter of the resultant crater. Impact of a hypersonic meteoroid probably could generate a similar shock front at the appropriate scaled depth.

RECONNAISSANCE SEISMIC-REFRACTION STUDIES OF THE ALEUTIAN RIDGE AND THE BERING SEA

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Seismic-refraction profiles have been made on the Aleutian Ridge near Adak and in the Bering Sea near Adak and Unimak. The western (deep) portion of the Bering Sea has structure of oceanic type,

similar to the Pacific Basin, but has a greater accumulation of sediment. The Aleutian Ridge is composed of material with velocities and layering similar to those found under Pacific volcanic islands and is underlain by material with a velocity close to 6 ¾ km/sec, typical of the oceanic crust.

Profiles at the top and foot of the continental slope near Unimak, on the eastern edge of the Bering Sea, have depths to the M discontinuity intermediate between continental and oceanic values. The eastern shelf itself, at least near its edge, is composed of low-velocity material, probably sediment.

RELATION OF FRONT RANGE MINERAL BELT TO ANCIENT PRECAMBRIAN STRUCTURES

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The Front Range mineral belt is a relatively narrow zone characterized by metallic ore deposits and associated porphyritic igneous rocks of early Tertiary age. The belt trends northeast, diagonally across the axis of the Front Range, and it cuts across the major structural and lithologic elements of the range.

Recently completed geologic mapping in the central part of the Front Range indicates that the mineral belt is alined along an ancient structural trend in the Precambrian basement rocks. This trend resulted from deformation that formed linear zones of small folds accompanied by cataclasis; the small folds are superposed on older plastic folds that control the gross distribution of the Precambrian rock units. Near Idaho Springs these linear zones trend N. 55° E., are remarkably straight, and are most abundant in a belt about 2 miles wide that lies along the southeast margin of the mineral belt. They extend northeast to the edge of the Front Range highland and probably for some distance southwest as well. Presumably the cataclasis was a deep-seated expression of faulting that occurred in the late Precambrian.

We infer that the linear zones of granulated and folded rocks represent an old zone of structural weakness that extended deep into the crust and was a fundamental control of the mineral belt. This belt was reactivated during the Laramide orogeny and was the locus for generation of the magma that was responsible for the formation of the ore deposits.

PHYSICAL PHENOMENA IN ARID-ZONE HYDROLOGY

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A study in arid-zone hydrology must entail an analysis of the processes of water movement in all its forms: liquid, vapor, and solid. Arid regions are characterized by the large amount of water that leaves the system in vapor form. The development of water by man is largely one of converting the liquid water to water vapor—mostly by the cultivation of crops—or in converting water that leaves in the vapor state, prior to development, for more beneficial routes of vapor removal.

In most arid regions man soon finds that his water demands, present and potential, far exceed the water that is available perennially. This additional water must come from water reserves that have been stored in the basin prior to development. Such water is found in the pore spaces of the rocks of the earth's mantle. The hydrologist must eventually become interested and concerned about the storage characteristics of this mantle. A study in arid-zone hydrology will then generally center around a geologic analysis of the ground-water reservoir and a study of water utilization in the region.

POST-GLACIAL PHYSICAL HISTORY OF THE SOUTHWEST

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The mining of subsurface water in the Southwest is leading into intensive studies regarding the highly complex hydrologic cycle. It is essential to know why, how, and when the water is accumulated in the basins if we are to have wise planning on how men can continue to use and occupy this area.

The reconstruction of past climate is based on plant and animal remains and upon sediments deposited during the time in question.

Studies on the pollen grains extracted from sediments enable us to have some idea of the plant life; similar studies on animal remains give clues to the fauna. Studies in erosion and in sedimentation are providing information regarding the dynamics of climate. Precise dating of the sediments is possible through the use of radiocarbon, dendrochronology, and archaeological materials.

SEARLES LAKE EVAPORITES AS AN INDICATOR OF THE TEMPERATURE-PRECIPITATION BALANCE IN LATE QUATERNARY CLIMATES

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Searles Lake basin, southeastern California, contains Quaternary evaporites that furnish a detailed record of late Cenozoic climates of the region. During pluvial periods believed equivalent to the Sierran Tahoe and Tioga glacial stages of Blackwelder (1931), Searles Lake was the third in a longer series of basins that became integrated into a chain of lakes chiefly fed by water from the east side of the Sierra Nevada. During interpluvial stages, Searles Lake became a saline lake or a salt flat.

Twenty discrete layers of muds and salts, believed deposited in Tahoe-to-Recent time, form a record of expanding and shrinking stages of the lake. These fluctuations are tied to an absolute time scale by 18 C^{14} dates of which the oldest is 46,000 years. Phase data for chemically precipitated minerals in each layer indicate the concentration of dissolved solids and/or the temperature on the lake bottom at the time of precipitation. The additional information given by these mineral assemblages more closely defines the balance that existed during each stage between temperature, precipitation, and other climatic variables. Pollen data independently support most of the inferred climates.

By stratigraphic inference, these stages can be related to the glacial history of the Sierra Nevada. If the climates of the two areas fluctuated similarly, it can be inferred that each glacial and interglacial stage resulted from a slightly different combination of climatic stability, temperature, and precipitation.

ALASKA EARTHQUAKE OF JULY 10, 1958

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With the data gathered from the study of the records of 125 stations, the epicenter of the Alaska earthquake of July 10, 1958, was determined, and the residuals in arrival times have been studied for all stations. The character of the *P* waves as a function of azimuth is considered for its significance with regard to the fault-plane solution. The fault-plane solution itself is presented. This solution is in general agreement with observed surface faulting. Finally, the long-period, well-developed *S* waves observed at many stations in this earthquake are investigated and correlated with the mechanism at the focus of the earthquake. Both *SH*, *SV*, and where possible the plane of polarization of *S* are used for this purpose.

SAN FRANCISCO EARTHQUAKE OF MARCH 22, 1957: ENGINEERING OBSERVATIONS

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The earthquake of March 22, 1957, had its instrumental epicenter about 3 miles south of the San Francisco City limits and was strong enough to cause about $1,000,000 loss to buildings. The shock was of magnitude of 5.3, but there had been eight shocks with as great or greater magnitude in California and Nevada in the 3 years previous.

Wood frame dwellings of a type somewhat peculiar to the San Francisco area suffered damage because of weak first-story front walls and a lack of interior first-story partitions.

No differences were noted in the damage patterns to houses located on cuts and fills in newer sections of Daly City. Engineering control when the fills were placed had frequently resulted in an increased density over that of the natural material in place.

One not fully explained anomaly was the heavier than average damage in the Westlake Palisades housing tract. The type of construction and foundation material was the same as that near by, yet the Westlake Palisades tract suffered considerably more than elsewhere. Possible explanations involve lurch and slumping effects on a major scale.

Multistory building damage was slight and usually consisted of partition damage and/or pounding damage between structures. Earthquake-resistive buildings, when flexible, suffered equally with those not designed to be earthquake resistive. A group of identical 10-story buildings had unusual but predictable damage patterns; each structure apparently acted dynamically as three coupled masses.

OCEANIC RAYLEIGH-WAVE DISPERSION IN THE PERIOD RANGE 15–140 SECONDS: THE GROUP-VELOCITY MAXIMUM AND ASSOCIATED AIRY PHASE

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Rayleigh waves recorded at Suva, Fiji, on Columbia long-period seismographs from four circum-Pacific belt earthquakes exhibit periods greater than the period of the group-velocity maximum, U_o, near 35 seconds. Resulting dispersion curves between 15 and 140 sec period have U_o equal to 4.02, 4.02, 3.98, and 3.98 km/sec at periods T_o, to 42, 42, 34, and 32½ sec for waves from Andreanof Islands, Fox Islands, Gulf of California, and southern Peru shocks, respectively. Energy from the Airy phase associated with U_o is evident on the seismograms more than 1 minute preceding the arrival time of U_o. The observed Airy phase agrees well with the theoretically predicted disturbance before and for some time after the arrival time of U_o. The first few minutes of the Rayleigh-wave trains were reconstructed using the Airy-phase contribution for times earlier than the time of U_o and constant amplitude trains whose frequencies were determined from the observed dispersion curves for later times. The fit is good although neither amplitude variations nor instrument-phase shift were considered. Because of the Airy phase, the apparent velocity of the beginning of the Rayleigh-wave train depends upon epicentral distance and seismogram-trace amplitudes. Errors of as much as 0.14 km/sec would arise from the improper interpretation of the apparently impulsive beginnings of the observed wave trains as the arrival time of U_o. The southern Peru shock (U.S.C.G.S. focal depth 100 km) was notable for lack of energy at periods less than T_o.

GEOLOGY OF THE ROCKY REACH DAM SITE, COLUMBIA RIVER, WASHINGTON

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Rocky Reach Dam is being constructed on the Columbia River approximately 7 miles upstream from Wenatchee, Washington. The dam will be 5000 feet in length consisting of an L-shaped, gravity concrete structure 3000 feet long and an impervious grouted cut-off extending 2000 feet into the gravels and clays on the eastern side of the valley.

At the site the river channel is filled with fluvial and lacustrine deposits on the eastern side of the valley. There are three main members in this series—upper gravels about 80 feet thick, varved clays 60–80 feet thick, and lower gravels up to 170 feet thick. The Columbia River now flows on a shelf of bedrock composed of Swakane gneiss which, locally at least, is a quartz-biotite granulite schist.

Excavation in the schists has revealed low-dipping planes of parting parallel to the schistosity.

Many faults in the schists have undulating fault surfaces. Where the largest fault zone passes under a heavily loaded powerhouse wall the fault gouge and breccia are being mined out and backfilled through 36-inch calyx drill holes.

On the east bank a long and deep trench has been cut through the upper gravels to the top of the varved clays. Along the bottom of this trench several lines of grout holes will be drilled through the varved clay and will penetrate the gravels underneath until bedrock is reached. The grouted gravels will serve as an impervious curtain with drainage provided on the downstream side.

MANTLE RAYLEIGH WAVES AND MANTLE STRUCTURE

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Variational calculus methods are applied to the problem of dispersion of mantle Rayleigh waves. The methods are relatively simple compared to multi-layer approximations and work well. So far we have worked two models of upper-mantle structure. One is the Gutenberg model in which we have a low-velocity layer around 150 km depth. The other is a modified Jeffreys-Bullen model in which the Jeffreys-Bullen model is modified above 200 km depth so as to join smoothly the data just under the M discontinuity. No low-velocity layer is assumed in this model. Both models give almost identical theoretical dispersion curves which agree well with the Ewing-Press observations of mantle Rayleigh waves for periods longer than 250 sec. The result means that the minimum-group velocity at about 250 sec is mainly due to a sharp increase of shear velocity at about 500 km depth, which is a common feature for the above two models. For periods shorter than 250 sec, Gutenberg's model gives results concordant with the observations. The modified Jeffreys-Bullen model disagrees significantly with the observations. The result demonstrates the existence of a low-velocity layer in the upper mantle.

An argument is presented to explain the flattening of the group-velocity curve for periods greater than 400 sec in terms of curvature of the earth and not vanishing rigidity in the core.

CRUSTAL SECTION ACROSS THE PUERTO RICO TRENCH

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A crustal section across the Puerto Rico Trench, from 450 km north of San Juan to 250 km south of San Juan, was deduced from seismic-refraction and gravity data. The result is a refinement of previous work made possible through more extensive seismic-refraction coverage and a program for high-speed electronic computation of two-dimensional gravity problems. Based on the refraction data, the crust was divided into five layers having compressional wave velocities of 1.54, 2.1, 3.8, 5.6, and 7.0 km/sec. Densities taken from a density-velocity curve compiled by Nafe and Drake are 1.03, 2.0, 2.4, 2.7, and 3.0 gm/cc respectively. Depths to the M discontinuity were computed from the gravity data using subcrustal density of 3.4 gm/cc, predicted by the density-velocity curve for 8.2 km/sec seismic velocity. (A similar calculation was made using 3.3 gm/cc.) Depth to M under the Trench is about 20 km and decreases sharply on both sides. Northward it reaches a minimum of about 10 km under the Outer Ridge, then deepens gradually to about 13 km under the southern margin of the Nares Basin. South of the trench M rises under the Puerto Rico shelf to about 17 km then deepens sharply to about 30 km beneath Puerto Rico. South of Puerto Rico the depth decreases again to about 14 km under the Venezuelan Basin.

Depths to M were obtained using Airy isostatic anomalies assuming constant crustal density of 2.67 gm/cc overlying a mantle of density 3.27 gm/cc. The crustal section thus deduced differs significantly from that obtained above where density variations within the crust were considered.

FIELD OBSERVATIONS ON THE EFFECTS OF THE ALASKA EARTHQUAKE OF JULY 10, 1958

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The Alaska earthquake of July 10, 1958, was caused by movement on the Fairweather fault. The maximum faulting observed was near Crillon Lake, where the northeast side moved down 3½ feet and southeast 21½ feet relative to the southwest side. Strike of the fault at that point is N. 41° W.; the dip is steep to the northeast.

Effects of strong shaking were evident over a large area in southeast Alaska and included earth slumps, lurches, rock and soil avalanches, earth flows, minor cracks and fissures, and the ejection of sand and silt from vents and fissures.

In Lituya Bay an enormous wave, probably resulting from a rockslide, reached a maximum height of more than 1700 feet. It destroyed two fishing boats and took two lives and resulted in the almost complete destruction of nearly 4 square miles of forest along the shores of the bay.

Three lives were lost on Khantaak Island in Yakutat Bay, where a beach sank, apparently as a result of a largely submarine slump.

CREEP ON THE SAN ANDREAS FAULT

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A large warehouse near Hollister, California, has been experiencing progressive distortion as a result of differential movement of the ground under it. The ground movement cannot be explained by gravity slumping or landsliding, since it is in a direction nearly perpendicular to the gradient of the gentle slope on which the warehouse is built. The resultant structural damage is confined to a narrow line across which the building is being sheared slowly into two sections.

The building is located in the San Andreas fault zone about 10 miles southeast of the southeasternmost point of surface-fault breakage in 1906. Movement is right lateral and is the result of slow creep across a line parallel to the fault zone at this point. A concrete floor slab poured against a wall in 1947 is now about 5½ inches away from the wall, for an average rate of half an inch per year. More detailed measurements begun in 1956 show that this ranged from zero in 2 weeks to 0.035 inch in 1 week. Periods of rapid creep do not seem to coincide with periods of higher than average local seismicity.

Continuous length of the line of creep is not known but is at least 200 yards. Within that distance, three spring houses have suffered right-lateral distortion, rows of vines and a concrete ditch have been offset, and, over the years, a buried water line has ruptured several times at the same point.

THRUST FAULTS IN SOUTHEASTERN LINCOLN COUNTY, NEVADA

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Many remnants of thrust plates were mapped between the Mormon Mountains and the Utah State line during a reconnaissance geologic study of Lincoln County, Nevada. Carbonate rocks of Cambrian to Mississippian age have moved eastward more than 14 miles on a nearly horizontal surface which may be erosional. The thrust plate is underlain by folded Triassic rocks belonging to the Moenkopi, Shinarump, and Chinle formations. Remnants of the thrust plate are exposed in a north–south belt 19 miles long, and the original extent was probably much greater. Pennsylvanian and Permian rocks in the center of the area are partly autochthonous and partly thrust or dragged eastward over Mesozoic rocks. In the northeastern Mormon Mountains, pre-Mississippian rocks

are thrust on Permian and Pennsylvanian rocks, which are, in turn, thrust or dragged on Precambrian and Lower Cambrian rocks. All the thrust remnants in the Mormon, Beaverdam, and Muddy mountains are probably parts of a thrust plate of regional extent correlated with the Muddy Mountain thrust of C. R. Longwell, which was recently dated as Early Cretaceous.

This belt of major thrusting is in the thin eastern shelf section near the margin of the geosyncline in southeastern Nevada. Post-Mississippian uplift along the eastern margin of the geosyncline may have caused gravitational sliding, thus accounting for some of the complex structural relations.

SEQUENCE OF VOLCANIC ROCKS IN SOUTHWESTERN NEW MEXICO

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The Tertiary and Cretaceous volcanic rocks in Grant, Luna, and Hidalgo counties, in southwestern New Mexico, have been tentatively divided into five major units. These units are lettered "A" through "E", in order of increasing age. Some of the characteristics of each unit follow:

Unit A.—Upper basalts. This unit is the least extensive unit. The basalts overspread younger gravels in the intermontane valleys and are probably of Pleistocene-Recent age.

Unit B.—Upper andesites, basalts, and latites. The unit is best exposed north of Lat. 32° 30′ N., in the area studied. These volcanic rocks are in places interbedded with upper Tertiary consolidated gravels.

Unit C.—Medial rhyolites and latites. Rocks belonging to Unit C are widely distributed throughout the area. Rhyolitic pyroclastic rocks, flows, and welded tuffs are the most common rock types.

Unit D.—Medial andesites and latites. Unit D rocks are erratically distributed throughout the area. They generally are made up of volcanic rocks deposited during or after widespread granodiorite-monzonite intrusions in the region. An early Tertiary-late Cretaceous age is often assigned to these volcanic rocks.

Unit E.—Lower andesites, basalts, and latites. Unit E includes volcanic rocks of early Cretaceous age, as in the Little Hatchet Mountains of New Mexico, and of late (?) Cretaceous age, as in the Central district. The rocks of this unit are older than the granodiorite-monzonite intrusives mentioned under Unit D.

It is likely that each of these units corresponds to a stratigraphic group.

RIPPLE ROCK EXPLOSION AND ASSOCIATED EXPERIMENTS

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In preparation for the Ripple Rock explosion, a depth-charge program was set up in the waters around Vancouver Island, and *P* waves from 36 charges were observed at distances up to 200 km. The results were combined with those obtained from earlier shots, to yield crustal data for the area.

The main blast, consisting of 1300 tons of high explosive, was clearly recorded by field seismographs as far away as Banff, Edmonton, and Hungry Horse, and less clearly by more distant stations in the Canadian prairies. The results indicate considerable crustal thickening under the Rocky Mountains and Selkirk Range, but little or no thickening in the cosatal region or the British Columbia central plateau.

Two underwater blasts were set off 20 minutes before and after the main explosion, in the hope of providing more definite information on the crustal thickness below Ripple Rock. This part of the operation, however, was only partially successful, as the energy proved insufficient to give reliable observations in the *Pn* range of distances.

STRUCTURE OF BASIN AND RANGE PROVINCE IN ARIZONA

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The structure of the Basin and Range province in Arizona has resulted from periodic deformation and igneous activity which occurred most notably during Older Precambrian, at the close of Younger Precambrian, between Permian and Cretaceous, between Cretaceous and Tertiary, during Tertiary, and during Quaternary time.

Salient features of the Older Precambrian structure are east–west and north–south shear faults; folds and thrust faults of northeast to north and other trends; and associated large intrusive masses. These ancient structures fundamentally influenced subsequent structural development.

Paleozoic and Mesozoic sedimentation was relatively thin on a relatively high medial belt extending northeastward across Arizona, but outward from this belt the sediments thicken southeastward in the Sonoran geosyncline and northeastward in the Cordilleran geosyncline.

Sedimentation, vulcanism, and orogeny possibly occurred in southwestern Arizona during early Mesozoic time.

The Laramide revolution resulted in east–west and north–south shear faults; folds and thrusts of northeast to northward trends; and extensive igneous invasion. The known areas of intense Laramide deformation are confined to southeastern and central-western Arizona.

During Middle and late Tertiary and down to Recent time, the region has undergone intermittent deformation, volcanic activity, and sedimentation.

Special characteristics of the Arizona basins and ranges are discussed. The salient features are believed to be explained best according to the concept of wrench-fault tectonics.

COMPARISON OF SOME EARTHQUAKES IN EASTERN AND WESTERN UNITED STATES

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A number of seismograms of earthquakes occurring in the eastern and western parts of the United States have been examined for differences that might explain the observation that eastern earthquakes of a given intensity are felt over a much larger area than western earthquakes with the same epicentral intensity. Amplitude and period data are presented that indicate the difference may result from differences in the frequency spectrum of the shocks.

CORRELATION OF UPPER TRIASSIC AND LOWER JURASSIC FORMATIONS BETWEEN SOUTHWESTERN UTAH AND SOUTHERN NEVADA

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In southern Nevada, strata between the Moenkopi formation (Lower and Middle? Triassic) and the Aztec (= Navajo sandstone (Jurassic and Jurassic?) are divisible into three principal units: a basal unit of sandstone and conglomerate; a middle unit of variegated sandstone and bentonitic claystone; and an upper unit of reddish-brown nonbentonitic siltstone and sandstone which is separated from the middle unit by an unconformity and which has a transitional contact with the overlying Aztec sandstone. Most previous workers in Nevada have termed the basal unit Shinarump conglomerate and have placed the middle and upper units in the Chinle formation. The authors consider the basal and middle units the probable equivalents of the Shinarump and Petrified Forest members of the Chinle formation (Upper Triassic) in southwestern Utah. The upper unit is litho-

logically similar to the Moenave (Triassic?) and Kayenta (Jurassic?) formations of the Glen Canyon group in southwestern Utah, which are also separated from the Chinle formation by an unconformity. On this basis the upper unit is believed to be equivalent to the Moenave and Kayenta formations, although division of the upper unit into the two separate formations cannot be made.

In southern Nevada, a unit lithologically similar to the Chinle formation and unlike the Moenkopi formation is present between the unquestioned Moenkopi formation and the Shinarump(?) member of the Chinle formation. This unit, included by previous workers in the Moenkopi formation, is questionably retained in the Moenkopi until its relationships are further clarified.

STRATIGRAPHY AND PALEONTOLOGY OF BRAZER LIMESTONE IN SOUTHERNMOST PART OF LOST RIVER RANGE, IDAHO

W. W. Wornardt, Jr.

The Mississippian Brazer limestone constitutes part of the folded and faulted Paleozoic rocks which form most of the Lost River Range which lies between Arco and Howe, Central Butte County, Idaho. The Brazer limestone is composed of dark-gray to blue-black crystalline limestone in the lower part and light-silty-gray to light-brown-gray crystalline limestone in the upper part. In this area the Brazer limestone is 3939 feet thick. A wide variety of abundant corals characterizes the lower part of the formation, and many brachiopods were found in the upper part. Six coral zones were recognized. They are, in ascending order: *Ekvasophyllum sp.* zone, *Faberphyllum sp.* zone, *Naxaphyllum sp. A* zone, *Triplophyllites sp. Y* zone, *Caninia sp.* zone, and *Lophophyllum profundum* zone. The Brazer limestone is considered to be Morrowan to early Atokan in age. The six zones are similar to those described by Parks (1951) from northern Utah.

ABSTRACTS OF PAPERS SUBMITTED FOR THE MEETING IN CHAPEL HILL, NORTH CAROLINA, APRIL 16, 17, AND 18, 1959

APPLICATION OF MINERAL ENGINEERING AND MINERAL ECONOMICS TO THE INDUSTRIAL GROWTH OF THE SOUTHEASTERN UNITED STATES

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A new industry in a community creates an expanded, more stable economy. Careful planning is needed to absorb the impact on labor, housing, tax structure, and municipal services. The effect of mineral industries on the chemical industry serves to point out that mineral industries are "breeders" of others.

Contrasting viewpoints of the immediate future growth of mineral industries in the United States are presented, as regards the common basic metals, minerals, and nonmetallics. The future of the Southeast must be tempered with uncertainty as to the direction and extent of scientific developments. Some of the new processes utilizing low-grade materials or radically new techniques are discussed briefly.

The essential co-ordination of effort by the mineral economist, mining, mineral, and chemical engineer and metallurgist, and the support of the scientific work of the geologist, geophysicist, and geochemist are exemplified by the Georgia Tech mineral-development research program—considered to be unique for educational research institutions.

BIOTITE ALTERATION IN THE COUNTRY ROCK AT ORE KNOB, NORTH CAROLINA

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The Ore Knob copper deposit occupies shear zones which cut across, at low angles, the foliation planes of a quartz-mica-plagioclase gneiss in Ashe County, North Carolina. The mica is predominantly biotite. The most important sulfide in the deposit is pyrrhotite; copper occurs as chalcopyrite.

As the ore body is approached through several hundred feet of country rock the index of refraction of biotite (n_β) decreases generally. The amount of decrease is greatest adjacent to the thickest portion of the ore body. In general, the decrease of refractive index is paralleled by a decrease in total amount of biotite and an increase in muscovite which becomes the most important mica type near the ore body. Since this alteration is a function of nearness to the ore body and not to a particular layer of gneiss, it appears to represent a type of wall-rock alteration.

On the basis of X-ray diffraction analysis, as well as index measurements, it is believed that the biotite-index variation is related directly to the Fe/Mg ratio. The relative lowering of biotite index near the ore body, as well as decrease in total biotite, suggests that iron was removed from the wall rock during its alteration. Since no secondary minerals exist in the wall rock in sufficient quantities to account for the displaced iron, the iron may have been deposited in the shear zone, helping to build the ore body, or was perhaps carried out of the system entirely.

STRUCTURAL FEATURES OF THE GRANDFATHER MOUNTAIN AREA, NORTHWESTERN NORTH CAROLINA

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Sedimentary and igneous rocks of low metamorphic grade occur in the Grandfather Mountain area in the Blue Ridge province of northwestern North Carolina. Recent mapping confirms the hypothesis that these rocks are exposed in a window beneath an overriding plate of crystalline rocks. Major tectonic units within the window are an autochthonous terrain composed of clastic sedimentary rocks and associated mafic igneous rocks overlying retrogressively metamorphosed granitic gneiss, and an allochthonous terrain composed of clastic sedimentary rocks and dolomitic marble.

Autochthonous sedimentary rocks display cleavage dipping southeast or east parallel to axial

planes of folds overturned toward the west. A similarly oriented cataclastic foliation is prominent in the autochthonous basement gneisses but is absent from the allochthonous rocks in the window. Cataclastic foliation in rocks of the overriding plate dips west and north away from the window. The boundary of the overriding plate is marked by an abrupt structural discontinuity with autochthonous rocks. Structural contrast with the allochthonous window rocks is less distinct. Along the eastern boundary, foliation in both overriding and overridden rocks dips southeast.

Rocks within the window and outside it display a regional lineation pattern. Alined and smeared-out minerals, mineral aggregates, and lithic fragments constitute an *a* lineation trending northwest. Axes of crinkles and minor folds in phyllites and phyllonites constitute a *b* lineation trending northeast.

These structures are believed to have been produced by deformation that culminated in thrusting crystalline rocks of the Spruce Pine area and northeast Tennessee northwestward over rocks of the Grandfather Mountain area.

MINERAL MATERIALS FOR USE IN CONCRETE FOR NUCLEAR SHIELDING

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High density is the major factor in determining the effectiveness of concrete as a nuclear shielding material. Density can be increased by using heavy-mineral materials as coarse and fine aggregate. Because of its absorption of neutrons, water is an effective barrier for neutron shielding. Consequently a heavy mineral which contains water in combination has some advantages. Freedom of the mineral from impurities which will produce objectionable induced radiation is an important consideration. Structural soundness of the material, as well as the usual economic factors, is also important.

Sources of several heavy-aggregate materials in the southeastern States are considered and evaluated. These include limonite, barite, zircon, ilmenite, staurolite, and various rocks.

BEAUFORT, SOUTH CAROLINA, MAGNETIC LOW

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The writers have mapped a large horseshoe-shaped area of low anomalies near Beaufort, South Carolina. Beginning southwest of Charleston, it roughly parallels the coast a few miles inland to St. Helena Sound, where it opens seaward. It is separated from the sea southwest of Port Royal Sound by an area of high anomalies which continues an unknown distance south of Tybee Road at Savannah. The area of low anomalies extends into Georgia near Springfield and continues up the Savannah River valley south of Allendale, South Carolina. From there it can be traced some tens of miles northeast toward Lake Marion. It is bordered on the southwest and northwest by areas of high anomalies. Between the coastal and inland arms of the horseshoe lies the Summerville magnetic high.

The low may be attributed to topography on the buried basement and/or to structural-lithologic differences within the complex. Some recent evidence lends credence to the former interpretation.

GEOLOGIC AND HYDROLOGIC PROPERTIES OF WEATHERED CRYSTALLINE ROCKS IN THE PIEDMONT OF GEORGIA

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A study made in Dawson County, in co-operation with the Air Force and the Atomic Energy Commission, showed the thickness, mineralogy, and hydrologic properties of saprolite developed on metamorphic rocks. The saprolite is reddish brown, retains relic schistosity from the parent rock, and is about 60 to 130 feet thick. It consists mainly of kaolinite, gibbsite, and biotite vermiculite.

with traces of quartz, goethite, muscovite, and chlorite. One grain-size analysis shows 50 per cent sand, 25 per cent silt, and 25 per cent clay; another shows 31, 29, and 40 per cent, respectively. Water in the saprolite is soft, acidic, and low in mineralization.

The permeability of the saprolite increases with depth and is greatest in the zone of gradation between weathered and unweathered rock; most ground water occurs in that zone. The unweathered rock is relatively impermeable and has a low storage capacity. Laboratory analyses of undisturbed samples of saprolite from depths of 0.04 foot to 4 feet below the surface indicate a permeability coefficient of 0.007 to 8 gpd per square foot and a porosity of 33 to 55 per cent.

Pumping-test data indicate a transmissibility coefficient of 500 to 4000 gpd per foot. Estimated ground-water velocities range from 0.04 foot to 1.03 feet per day. In small areas, ground-water movement in the saprolite apparently is controlled by the relic schistosity. On a larger scale movement may be controlled by joints which cut the lithologic units at right angles to the strike and drain the separate blocks.

PETROGRAPHY OF PALEOZOIC SANDSTONES AND SHALES FROM BORINGS IN FLORIDA

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Sandstones and shales from 23 borings into the basement rocks of northern Florida were studied by thin-section and heavy-mineral analysis. They range in age from Ordovician to Devonian and come from depths of 3000 to 8000 feet. The arenites include orthoquartzites, micaceous quartzites, and several other varieties. Many are calcareous. In some quartzites the mica is aligned in parallel flakes that wrap around quartz grains. The shales are either red or black. The color of the red shales is due to minute blebs of hematite attached to the fine-grained mica in the groundmass. In some places pyrite has developed from iron released from hematite presumably in a reducing environment. The black shales are similar mineralogically but contain organic matter and much more pyrite.

The arenites contain a small quantity of heavy detrital minerals, but the shales contain none. Heavy minerals (0.12–0.06 mm grain diameter) in the arenites can be grouped into three assemblages with characteristic major minerals: (1) ilmenite, zircon, tourmaline, and rutile; (2) garnet, epidote, ilmenite; (3) ilmenite, garnet, tourmaline, glaucophane, and chloritoid. Fine- to coarse-grained quartzites and those with little mica contain group (1) assemblage; fine silty sandstones and sandy shales contain either group (2) or group (3) assemblages. The heavy minerals in (1) are well rounded, but in (2) and (3) the grains are somewhat angular. The ultimate source of these minerals was granitic and metamorphic rocks. Rounded grains in (1) suggest second- or third-cycle sediments. The heavy minerals may be a means of distinguishing different beds in the various borings.

CURRENT-ORIENTED STRUCTURES IN SOME UPPER DEVONIAN ROCKS IN WESTERN NEW YORK

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In the Upper Devonian rocks in the western half of New York, groove casts, flute casts, faint striations on bedding planes, and current ripple marks are the most commonly observed primary structures that show an orientation caused by the action of marine currents. *Fucoides graphica* of Hall and fragments of plants are the most frequently observed organic structures that show a similar current orientation. The long axes of most of these linear structures are approximately parallel to the trend of the current that formed them. The orientation of the crests and troughs of ripple marks, however, is approximately normal to the current trend. Flute casts, *Fucoides graphica* of Hall, and asymmetric current ripple marks show by their shape and orientation the direction of flow. The other structures show only the trend (that is, the azimuth and the back azimuth) of the current, but not the direction of current flow.

The azimuths of approximately 2000 current-oriented structures were recorded in the field. Diagrams similar to rose diagrams show that the current direction in the basin of deposition changed progressively as successively younger beds were deposited. Near the end of Geneseo time the currents flowed from the northeast. The current direction changed from east-northeast in early Sonyea time to east-southeast in late Sonyea time. In late Perrysburg time and during Laona time the currents flowed from the southeast.

GEOLOGY OF THE ALBEMARLE QUADRANGLE, NORTH CAROLINA

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Rocks of the Albemarle quadrangle, North Carolina, are members of the Volcanic Slate series, a group of undifferentiated metasedimentary and volcanic rocks which are exposed throughout the central and eastern Piedmont region from Virginia to Georgia. While these rocks have been observed with considerable interest for more than 100 years, little work has been done in North Carolina to establish their stratigraphy and structure.

Recent studies show that the rocks of the Albemarle quadrangle can be divided into at least four major units. The first three are, from oldest to youngest, (1) acid fragmental tuffs, overlain by (2) bedded argillite containing interbedded basaltic flows and tuffs, and grading upward into (3) a tuffaceous siltstone in part composed of graywacke and containing interbedded acid and basic tuffs and flows. Unit 4 consists of massive rhyolite flows which cap the major hills in the eastern part of the area. Relationships between the rhyolite and the other units are not thoroughly understood, but the rhyolite is thought to overlie disconformably both the fragmental tuffs and the argillites. Rhyolite dikes cut the lower units and probably are feeders for the rhyolite flows.

The bedded deposits form a large open syncline which occupies most of the quadrangle. In the southeastern part of the area a possible dome or anticlinal structure is indicated. Although minor displacements are common, no major faults have been recognized in the area.

NEW OCCURRENCE OF CRYSTALLINE LIMESTONE IN McDOWELL COUNTY, NORTH CAROLINA

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A reappraisal of the crystalline limestones of North Carolina has brought to light an interesting limestone that until recently has gone unnoticed.

The limestone is located west of Marion, east of the Blue Ridge Mountains, and is associated with schists and gneisses of Precambrian (?) age. It occurs in a series of four outcrops that are in almost perfect alignment and extend over a distance of about 9 miles. The line of outcrops strikes about N. 55° E. The individual outcrops strike N. 35°–60° E. and dip 15°–50° SE.

The limestone consists predominantly of two types. One is light gray, fine-grained, micaceous, and siliceous. The other is dark bluish gray, fine-grained, banded, micaceous, and siliceous. The true thickness of the limestone could not be determined because of the lack of exposures; however, at one outcrop calculations indicate a probable maximum thickness of about 60 feet.

At two of the outcrops the limestone is overlain by a white to light-gray, medium-bedded, feldspathic quartzite. The quartzite is predominantly fine-grained, but a few beds are conglomeratic. The base of the limestone is not clearly exposed. At the best exposure, however, there is a covered interval of about 100 feet between the lowest bed of limestone and a 12-foot section of alternating beds of quartzite and siltstone. The lowest bed of siltstone grades downward into a thick section of crenulated, garnetiferous mica schist.

The limestone appears to be locally faulted, and inferred evidence suggests that the limestone delineates a fault of considerable proportions.

CORRELATION OF LOWER UPPER DEVONIAN ROCKS IN CENTRAL NEW YORK

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A detailed study of the pre-Sonyea rocks of Late Devonian age in the area between Cayuga Lake and Canandaigua Lake showed that the Ithaca shale member of the Portage formation, which contains the Ithaca fauna in the vicinity of the city of Ithaca at the south end of Cayuga Lake, is equivalent to the upper one-third of the Geneseo shale, the Genundewa limestone lentil of the Geneseo shale, and the lower two-thirds of the West River shale in the vicinity of Naples at the south end of Canandaigua Lake. Previous correlations of the Ithaca shale member of the Portage formation with the Sonyea or post-Sonyea rocks proposed by earlier workers are incorrect. Revision and redefinition of units in the sequence of lower Upper Devonian rocks are necessary. The writers will propose a revision of the Genesee group similar to the Sonyea and West Falls formations.

TENTATIVE CHRONOLOGY OF METAMORPHIC-PLUTONIC EVENTS IN THE SOUTHERN APPALACHIANS, BASED ON NEW K/A AND Rb/Sr AGE DETERMINATIONS

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The plutonic history of the Southern Appalachians appears to include at least four metamorphic episodes. The oldest discernible event is recorded in basement rocks at Pardee Point, Tennessee (Rb/Sr = 890 m.y.), while the most prominent subsequent event is dated by pegmatites at Spruce Pine (K/A = 340 m.y.) and Gay (345 m.y.) in North Carolina. An intermediate event, the precise age of which is unknown, is established by the K/A age of 440 m.y. (minimum possible age) obtained from newly formed biotite and muscovite in the lightly metamorphosed Ocoee rocks, west of Ducktown, Tennessee. Corroborative evidence is obtained from the 445 m.y. age determination for biotite in amygdule-bearing basalt dikes at Red Hill, North Carolina, intrusive into brecciated Cranberry gneiss. The spread of ages from 310 m.y. (Gaffney marble, South Carolina) to 225 m.y. (granite, Cayce, South Carolina) for metamorphic rocks and so-called "Carboniferous" granites in the Piedmont provides evidence for a fourth event.

Progressively older apparent ages are obtained on proceeding north from Spruce Pine to Pardee Point. Petrographic observations of analyzed samples between the two localities are consistent with the proposal that partial recrystallization of intermediate rocks has occurred, producing a transition zone between least affected rocks at Pardee Point and completely recrystallized rocks at Spruce Pine.

CONTRIBUTIONS TO THE GEOLOGY OF THE COASTAL PLAIN OF NORTH CAROLINA

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Former studies revealed two structural features within North Carolina's coastal plain directed normal to the northeast-southwest trend of the main Appalachian structure lines. The first, the "Hatteras Axis", limited Triassic sedimentation to the south of it; later it influenced the sedimentation of the Early Miocene. The second is the "Cape Fear arch", along which the "basement rocks" are nearest the present surface.

Between these lies a third structural feature, the "Cape Lookout–Neuse fault zone". It limited Eocene sedimentation north of the Neuse River; no surface or subsurface occurrences of Eocene

sediments are known between Smithfield and Kinston, while south of the river Upper Miocene Yorktown sediments are replaced by the Duplin formation. The zone is marked, moreover, by a change from a flat slope to a steeper one on the "basement rocks" between the "Cape Fear arch" and "Hatteras axis", and by silicification (Oligocene geyser activity?) of the Eocene sediments at several places.

Another structural zone, parallel to the main Appalachian trends, exists along the eastern boundary of Martin, Pitt, and Lenoir counties; it influenced both Eocene and Miocene sedimentation. Where it crosses the "Cape Lookout–Neuse fault zone", the partly silicified Eocene limestone (Trent formation) occurs.

The three normal structural features controlled the asymmetrical development of the drainage areas of the Cape Fear and Neuse rivers on the coastal plain. Together with another parallel line, the rim of the continental shelf, they determined the locations of Cape Hatteras, Cape Lookout, and Cape Fear.

STATUS OF REGIONAL GRAVITY STUDIES IN NORTH CAROLINA

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Regional gravity studies in North Carolina have been extended to include all the coastal plain and much of the piedmont. With this coverage, gravity stations located in North Carolina by the current project have now been extended by nearly 2000 stations. In many areas surface geology is sufficient to explain anomalies; however, in the flat coastal plain, unusually large anomalies must be explained by subsurface interpretation. Where possible, areas in the coastal plain and in the piedmont which are anomalous are illustrated by profile and contour maps.

GEOLOGY OF THE CRABTREE CREEK AREA NORTHWEST OF RALEIGH, NORTH CAROLINA

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The Crabtree Creek area is underlain by a series of homoclinally dipping, regionally metamorphosed sediments and volcanic rocks striking northeast and dipping northwest. It is bounded on the northwest by the block-faulted Durham basin, which is filled with continental sediments of Triassic age, and on the southeast by anticlinal structures. The metamorphic rocks are gneisses, schists, and phyllites decreasing in metamorphic rank toward the northwest and ranging from the staurolite-kyanite subfacies of the amphibolite facies to the muscovite-chlorite subfacies of the greenschist facies. They are extensively intruded by quartz monzonite and diabase, as well as minor injections.

The major phase of regional dynamic metamorphism probably occurred in Ordovician-Silurian time and was accompanied or closely followed by injections of quartz monzonite. This was followed by at least one period of retrogressive metamorphism producing cataclastic textures in some places. Triassic normal faulting and diabasic intrusions were the last major disturbances. The area is now rejuvenated from a near old-age stage of erosion.

MONAZITE-BEARING PEGMATITES IN THE MID-SOUTH GEORGIA PIEDMONT

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Monazite is present in several places in a belt extending northeastward through Culloden, Monroe County, Georgia. At one place it follows a steeply dipping shear zone in augen gneiss. The gneiss

contains a pitchy, black biotite which does not weather as ordinary biotite does and which occurs in irregular bands between potassium feldspar and granulated quartz.

At another place monazite in fairly large monoclinic crystals occurs at right angles to the sheared monazite zone, which is oriented nearly parallel to Appalachian structure. These large monazite crystals are plentiful in certain areas and can be easily detected by a Geiger counter. Quartz, feldspar, or kaolin are not associated with the monazite crystals at this locality.

NEW EVIDENCE IN SUPPORT OF A DETRITAL ORIGIN FOR THE UPPER CRETACEOUS KAOLIN DEPOSITS OF THE SOUTHEASTERN UNITED STATES

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The petrography and parameters of sedimentary petrogenesis of the Providence formation (Upper Cretaceous) in its type locality at the Providence Canyons near Lumpkin, Georgia, are presented as evidence for the possible detrital origin of many of the kaolin deposits of the southeastern United States. The formation, along its outcrop edge in southwestern Georgia, is a clastic unit composed of two members, the upper of which is a feldspathic, cross-bedded, conglomeratic sandstone. Petrographically, it consists of 5–50 per cent plagioclase feldspar, 1–3 per cent potassium feldspar, quartz, muscovite, traces of chert and rock fragments, and up to 20 per cent kaolin grains in all size ranges. The conglomeratic nature of the sandstone is manifested in scattered rounded vein-quartz pebbles up to 1 inch in diameter; partially kaolinized subhedral feldspar crystals up to half an inch long; and cobbles, boulders, and pebbles of almost pure kaolin. Discontinuous beds consisting almost entirely of clayball conglomerate are associated with the coarsest sand sizes. Irregular lenses and pods of kaolin up to several yards long and of differing degrees of purity are interbedded and intercalated throughout the sandstone. Kaolin pebbles, boulders, and cobbles weathered from the Providence formation have been found in transportation in the streams draining the canyon area, proving their durability in short-range transport. The provenance areas, distribution system, environment of deposition, and diagenesis of the Providence formation are presented as deduced from its petrology.

The detrital nature of the kaolin in the Providence formation, together with the amounts of clay found, supports the clastic origin of similar deposits of kaolin within the upper Cretaceous.

PRELIMINARY STUDY OF THE TOWALIGA FAULT IN PIKE AND LAMAR COUNTIES, GEORGIA

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The Towaliga fault has been traced for about 21 miles. The main fault strike ranges from N. 60° E. to N. 90° E. and the dip from 30° to 70° NW. Mylonite is best developed along the main fault but also occurs in smaller outcrops on either side.

The most abundant kind of mylonite is a megascopically poorly foliated, white "flinty crush rock" which is composed of uniformly crushed quartz. A second type often occurs in deformed quartz veins. This mylonite shows a strong megascopic foliation and is composed of augen of translucent quartz interwoven with undulating layers of white, crushed quartz. A third variety contains irregular blocks of porphyroblastic biotite-feldspar gneiss bounded by anastomosing veinlike mylonite.

Two major joint sets, one striking about N. 60° W. and dipping 70° SW. and the other striking N. 75° E. and dipping 65° SE. roughly bisect the lineation on the fault planes. Another set occurs most commonly in the mylonite. This set strikes about N. 85° W. and dips 85° SW.

Quartz veins, although more widely scattered than joints, show two trends. The one which strikes N. 78° W. and dips 55° NE. is roughly parallel to the main fault trend. The other set strikes N. 55° E. and dips 85° SE.

ORIGIN OF RING-SHAPED WEATHERING PITS AT STONE MOUNTAIN, GEORGIA

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Shallow circular weathering pits, 2–6 feet in diameter, are conspicuous on gently sloping granite surfaces at Stone Mountain, Georgia. Many are ring-shaped; the rim is deeply etched, but the center stands up as a mound. The ring pits are too numerous and well developed to be merely fortuitous.

The ring pits are developed in thinly exfoliating granite, generally where weathering has breached the uppermost, partly detached shell. The next lower shell, bulged up like a blister, forms the central mound. A slight opening beneath the blister is inferred from the hollow sound resulting from a hammer blow. Where weathering has breached some blisters the opening is visible.

The principal cause of exfoliation at Stone Mountain is granite expansion accompanying release of original high confining pressure, as erosion strips away the cover. Where stresses generated by expansion exceed the rock's tensile strength the outer, more rapidly expanding layers burst loose.

During exfoliation the rock expands outward, toward the erosion surface, but remains confined laterally. Lateral expansion becomes possible, however, for the uppermost shells, which bow upward ("blister") from the underlying rock to accommodate their slight increase in surface area. The blisters, once formed, are especially vulnerable to weathering; water works beneath, attacking the thin shells from below as well as above. Breaching of the blistered uppermost shell forms only a simple circular pit. This may develop into a ring pit if the shell beneath also blisters. Water then collects around the low margins, weathering them more deeply.

MAYSVILLE EARTH SLIDES

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During the Spring of 1958, from April 26 to May 12, a series of very destructive earth movements on a steep talus slope took place in a hilly suburban area bordering the south shore of the Ohio River immediately northwest of the city of Maysville, in Mason County, Kentucky. Estimates of the damage done to State and private property in the area of the movement by the rifts, slips, and slides developed during this period ranged from $150,000 to $250,000.

This paper outlines a detailed and comprehensive study made on official, professional engagement on the ground, including an 8600-foot transit and stadia traverse, coupled with a close examination and integration of government and private seismic, precipitation, and flood records of the area. The origin and timing of these broadly spread 1958 earth movements in the talus deposits on slopes closely adjoining Maysville, Kentucky, is graphically and conclusively shown to have been due entirely to the combined natural phenomena of abnormal seismic activity, excessive precipitation, and high flood levels of the Ohio River.

AEROMAGNETIC SURVEY OF A MICA PERIDOTITE BODY IN UNION COUNTY, TENNESSEE

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A mica peridotite body near Maynardville, Tennessee, intrudes Hancock limestone (Silurian and Devonian) just below the Wallen Valley thrust fault. The peridotite has abundant accessory magnetite and some garnet. A local aeromagnetic survey shows that the peridotite body gives rise to a single sharp symmetrical anomaly which indicates that the areal distribution of the intrusive rock is not appreciably greater than the outcrop area, and that the body probably does not dip southeastward along the trace of the Wallen Valley fault. The local peridotite anomaly is at the crest of a much larger regional anomaly.

A large anomaly at New Tazewell, Tennessee, 15 miles northeast of the one at Maynardville, is of the same character. A similar anomaly has been recorded also on a cross-country traverse about 10 miles southwest of Maynardville. The occurrence of peridotite on one of the large anomalous trends suggests the possibility of other intrusive activity beneath the Appalachians in the area, but the extent and nature of the activity cannot be appraised from available aeromagnetic information.

RECENT SUBSURFACE INVESTIGATIONS IN THE WELLS CREEK STRUCTURE, STEWART COUNTY, TENNESSEE*

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The major geological features of the Wells Creek structure in Stewart and Houston counties, Tennessee, have been known for about 100 years, but many details remain unknown because of the lack of sufficient outcrops in critical areas.

In 1958 the Tennessee Valley Authority drilled 53 core-drill holes on a 200-foot grid covering an area 1400 feet by 1200 feet near the northern edge of the central part of the disturbance. Fifteen formations ranging in age from Mississippian to Ordovician were identified in the cores. This drilling indicated that the geologic structure is far more complex than can be deduced from any surface evidence.

On the basis of the detailed data obtained from the drilling, a tectonic origin for the structure is considered possible. This theory postulates that the area was the focus of regional tectonic stresses accompanying the downwarping of the Mississippi embayment. These stresses—tensional near the surface and compressional at depth—finally exceeded the elastic limit of the strata overlying the basement, resulting in a violent eruption.

GEOLOGIC FEATURES OF THE ORE KNOB COPPER MINE, NORTH CAROLINA

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The Ore Knob vein is a massive sulfide body that occurs in a "Carolina" type Precambrian gneiss. The main ore shoot is a troughlike body 3500 feet long that has been localized by two intersecting normal faults. Thickness of the ore shoot appears to have been controlled by three main factors: (1) dip change in the fault planes, (2) the intersection angle of the two fault planes, and (3) wall rock that was more or less susceptible to replacement. The keel of the sulfide body appears to be marked throughout by a zone of quartz-hornblende-actinolite gneiss.

Two main types of mineralization are present: massive pyrrhotite-pyrite-chalcopyrite that contains healed fragments of wall rock; and disseminated to massive granular pyrite with a little chalcopyrite and pyrrhotite. The disseminated to massive pyrite contains relic wall-rock structure.

SAPROLITE AND GROUND-WATER PROFILES IN THE CRYSTALLINE ROCKS OF THE SOUTHERN APPALACHIANS

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In the crystalline rocks of the southern Appalachian piedmont a great local variation exists in the depth of weathering, in the depth of the water table, in the relative positions of these two depths, and in the depth to the base of fractures that are sufficiently large to carry water.

Criteria are being developed that may ultimately lead to reasonably accurate predictions of these depths at specific sites. These criteria will be developed from an understanding of the causes and effects of porosity-permeability features in relation to geomorphic processes. Examination of several

* Publication authorized by Tennessee Valley Authority.

thousand well records and personal observations permit an averaging of these depths beneath prevailing slopes. Profiles of typical piedmont terrane showing mean positions of the water table, fresh-bedrock surface, and base of water-bearing fractures reveal many significant points, among which are the following: (1) The upper ground-water medium, in which water moves *en masse* through porous granular material, includes the soil, subsoil, and upper part of the saprolite. (2) The lower medium, in which movement of water is confined to fractures, includes the lower part of the saprolite and no more than a few tens of feet of fresh rock. (3) The water table generally lies in the saprolite. (4) In the lower medium both the number and size of visible fractures tend to decrease markedly with increased depth.

The mean profiles offer norms from which local pertinent variables may be evaluated.

DEFORMATION IN PEGMATITES OF THE SPRUCE PINE DISTRICT, NORTH CAROLINA

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Recent studies by the U. S. Geological Survey in connection with Defense Minerals Exploration Administration investigations indicate that many mica-bearing pegmatites in the Spruce Pine district of North Carolina have been deformed cataclastically. Brecciated feldspar crystals, granulated quartz masses, and sheared muscovite books are common in many of the pegmatites. Lineations on shear planes in the pegmatites are parallel to the regional northwest-trending lineations of the wall rocks. Sheared muscovite books are bent, ruled, and edge-cracked. Some books are coated with crushed muscovite. The granodiorite ("alaskite") intrusives in the district are also sheared and crudely foliated. Lineations on this foliation trend northwest.

Intensity of shearing apparently increases toward the margins of the district. Pegmatites near Plumtree in the east, Burnsville in the west, and Bakersville in the northwest are generally more sheared than those nearest Spruce Pine.

The amount of shearing in an individual pegmatite is apparently controlled partly by structural attitude and partly by wall-rock lithology. Simple tabular pegmatites are generally not so strongly sheared as contorted "S"-shaped ones. Pegmatites enclosed by thick masses of coarse mica schist are less deformed than those enclosed in mica or hornblende gneiss.

Perhaps the shearing is related to the period of deformation that culminated in the Grandfather Mountain thrust fault which is exposed along the west side of the Grandfather Mountain window a few miles east of the district. The pegmatites, which were deformed along with the metamorphic rocks of the thrust sheet, may have been moved a long distance from the east.

NOTES ON THE SOUTHEASTERN ALASKA EARTHQUAKE OF JULY 1958

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In the evening of July 9, 1958, a major earthquake (magnitude 7¾) occurred along the western edge of the Fairweather Range, Alaska. Seismic records and other data are being compiled and studied by Don Miller of the U. S. Geological Survey, Dr. Don Tocher of the University of California at Berkeley, and personnel of the Coast and Geodetic Survey. Observations in the vicinity of Lituya Bay indicate that the quake was responsible for at least one, and possibly two, gigantic waves, plus numerous slides and rock falls. Waves plus slides denuded great forested areas along the edge of the bay; the destruction by slides extended to a maximum elevation above sea level of 1800 feet. Only two fishing boats and two people were lost in Lituya Bay as a consequence of this quake; however, if the area had been densely populated the loss of property and life would have been catastrophic.

MISSISSIPPIAN STRATIGRAPHY OF THE NORTHWESTERN HIGHLAND RIM IN TENNESSEE

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Rocks of Mississippian age, which include the New Providence, Fort Payne, Warsaw, St. Louis, and Ste. Genevieve formations, underlie the northwestern Highland Rim in Tennessee. Locally, the Mississippian rocks are capped with outliers of gravel of the Tuscaloosa formation of Late Cretaceous age. The lowermost Mississippian formation, the New Providence, consists of greenish-gray clay shale and dense light-colored limestone. The overlying Fort Payne chert is subdivided laterally into three lithofacies, which, for field purposes, are called bedded chert, scraggy chert, and shaly chert. Overlying the Fort Payne with apparent conformity, the Warsaw limestone consists of coarse-grained massive fossil-fragmental calcarenite. Lithologic heterogeneity characterizes the St. Louis, but in general it is a fine-grained dark cherty limestone. Fossil-fragmental calcarenite and oölitic, shaly, and dolomitic limestone also occur in the St. Louis. The Ste. Genevieve limestone, a white noncherty oölite, is known from only three surface exposures but is present in the subsurface of Montgomery County.

Structurally the northwestern Highland Rim is an area of broad, gentle folds. Several high-angle normal faults with displacements of as much as 250 feet have been mapped. Although the evidence is yet inconclusive, most of the faulting appears to have taken place either during, or subsequent to, deposition of the Tuscaloosa formation.

INVESTIGATIONS OF HIGH-SILICA SANDS AND SANDSTONES IN KENTUCKY

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State-wide geological investigations of industrial rocks and minerals in Kentucky have included an attempt to appraise the known deposits of high-silica materials and to ascertain the presence and extent of others. Results of these efforts have been the location and delineation of several deposits which have definite economic value.

Upper Mississippian and lower Pennsylvanian sandstones, and sands of the Ripley formation (Cretaceous) offer the greatest economic possibilities. Deposits ranging in size from 3,000,000 tons to more than 20,000,000 tons have been located. Iron-oxide content as low as 0.035 per cent in the raw sample has been noted. Of particular merit are a deposit of Ripley sand in Calloway County near Kentucky Lake and a deposit of Lee conglomerate on Pine Mountain near Elkhorn City, Pike County.

Potential uses include abrasive, engine, foundry, and glass sands, metallurgical silica, refractories, and railroad ballast.

STRUCTURAL GEOLOGY OF THE SEQUATCHIE VALLEY IN TENNESSEE

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Detailed geologic mapping of the Sequatchie Valley north of Dunlap, Tennessee, has disclosed that the Sequatchie Valley fault generally dips 10°–20° SE. The low-angle attitude of the overthrust fault is evidenced by the irregular trace of the fault and a series of klippen immediately in front of the overthrust block.

Reconnaissance mapping south of Dunlap indicates that the trace of the fault is considerably straighter than the trace north of Dunlap. From this observation, and the observations that both

the stratigraphic displacement and depth of erosion of the structure increase from north to south, it is concluded that the dip of the fault steepens at depth.

Rock units mapped by the writer in this investigation are: the upper part of the Knox group succeeded by alternating massive and slabby bedded Ordovician limestones correlative to those of the Nashville basin, having a total exposed thickness of approximately 2000 feet; 20–25 feet of Silurian (Brassfield) limestone; 20–30 feet of Devonian-Mississippian (Chattanooga) shale with the thin Maury shale at the top; 160 feet of Fort Payne chert; 385 feet of "Newman" limestone; 165 feet of Pennington shales, limestones, and sandstones of Mississippian age; and, at the top, 200-300 feet of Pennsylvanian shales and sandstones.

South of Dunlap, the Knox group is in fault contact with autochthonous massive Mississippian "Newman" limestone. North of Dunlap rocks of the allochthone, Knox group to "Newman" limestone, are in fault contact with autochthonous Pennington shales, sandstones, and limestones.

GEOLOGY AND STRUCTURE OF SMITH MOUNTAIN AND ADJACENT AREAS IN BEDFORD AND PITTSYLVANIA COUNTIES, VIRGINIA

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Smith Mountain, a mountain of circumdenudation in the eastern piedmont region of Virginia, is an anticlinal mountain composed of metamorphosed Precambrian rocks which lie below the Lynchburg gneiss and make the core of Smith Mountain. These metamorphic rocks are quartz-chlorite chloritoid gneiss. West of Smith Mountain the Lynchburg formation is faulted on its western edge. West of this fault are undifferentiated Precambrian rocks. At the eastern foot of Smith Mountain the Lynchburg formation is well exposed in a belt about 1 mile wide and is bounded on its eastern edge by the Swift Run formation composed of massive quartzitic sandstone with some volcanic rocks. East of the Swift Run formation, and lying on top of it, is the Catoctin greenstone which makes a belt approximately a mile wide. On top of the Catoctin is the Loudoun formation which is bordered on the east by the Everona formation. The Everona in this area is a white marble. Staurolite schist has been thrust over the Everona in places, so that it does not crop out, and the Loudoun formation occurs west of the staurolite fault.

A number of diabase dikes in this area extend in almost a north-south direction. Several faults have been located in the Smith Mountain gorge, and others cut across the river at almost right angles. The faults are both normal and high-angle reverse faults.

LARGE "REEF" IN THE MAYNARDVILLE LIMESTONE, TENNESSEE

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The following five zones were found in the Maynardville limestone, from the base upward, in an area in Jefferson County, Tennessee, about 1½ miles north-northwest of Douglas Dam.

Zone 1: 40–70 feet of interbedded limestone and shale

Zone 2: 166 feet of massive stromatolitic limestone

Zone 3: 130 feet of oölitic and conglomeratic limestone and calcareous sand

Zone 4: 180 feet of massive to heavy-bedded limestone, with a few dolomitic and stromatolitic layers

Zone 5: 60–70 feet of thin-bedded dolomite.

A sizeable "reef" is indicated by large subcircular algal colonies in Zone 2. The individual colonies are bounded by bands and irregular areas of detrital limestone and fine-grained dolomite. These "intercolony fillings" are believed to have been calcarenites and calcareous muds eroded from the "reef" and washed into channels formed by currents.

The thick stromatolites of Zone 2 resemble a reef core, and the thin-bedded dolomites of Zone 5 a lagoonal facies. Thus, the Maynardville strata appear to have formed, at least in places, banks

or, possibly, barrier reefs which led to the deposition of the overlying Knox dolomite in very shallow water.

GEOLOGY AND HYDROLOGY OF THE GROUND-WATER DISPOSAL AREAS AT SAVANNAH RIVER PLANT, AIKEN, SOUTH CAROLINA*

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Unusual opportunity was afforded the writer to make detailed geologic and hydrologic maps and lithologic panel diagrams of the four principal ground-disposal areas for large volumes of low-level radioactive liquid and solid wastes at the Savannah River plant. The data of nearly 200 soil-exploration test holes were classified into 11 soil types according to texture and mineral composition as follows: (1) coarse sand, (2) medium sand, (3) fine sand, (4) silty or clayey sand, (5) sandy silt, (6) coarse sandy clay, (7) medium sandy clay, (8) fine sandy clay, (9) silty clay, (10) clay, (11) fat clay. This sequence from coarse to fine therefore shows decreasing porosity and permeability but increasing ion-exchange capacity per unit volume. These soil-texture numbers, rather than the age of each stratum, were then used as the basis for soil correlations between drill holes. The resulting lithologic panel diagrams gave a useful semiquantitative picture of those physical and chemical properties of the various soil strata important in predicting the direction and rate of migration of low-level radioactive liquids. Detailed contours drawn on top of the ground-water table as modified by enormous percolation from near-by seepage basins containing low-level radioactive liquids showed, by the pattern of the extension of high-elevation ground-water mounds and tongues, those areas and directions where escape of liquids from the seepage basins was most rapid. The extent of migration of radioactive liquids was determined by ground-water monitoring wells. The results checked closely with lithologic and hydrologic data and showed that detectable radioactivity traveled no farther than 125 feet before being decontaminated by the soils.

PLEISTOCENE MAMMALS DREDGED OFF THE COAST OF NEW JERSEY

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Bones and teeth of various mammals have recently been dredged by fishermen and clammers off the coast of New Jersey, especially between Atlantic City and Cape May. It is believed that most of them are of Pleistocene age and that they lived during a low sea-level stage of that epoch when the shore line was considerably east of the present beaches. The specimens recently collected include the mammoth, mastodon, horse, tapir, walrus, whale, musk ox, and giant moose. Similar fossil specimens are occasionally washed onto the beach between Long Branch and Cape May. One such record is of a ground sloth found many years ago at Long Branch. These occurrences are similar to some reported by Taber a few years ago from the beaches of South Carolina.

ASPECTS OF HEAVY-MINERAL DISTRIBUTION IN THE SOUTH CAROLINA COASTAL PLAIN

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Heavy-mineral tenors in the South Carolina Coastal Plain suggest a moderate degree of interrelation with past geologic processes and the development of present physiographic features. In coastal areas, at least three general distributive provinces are recognized in sands of the present-day beaches. Heavy-mineral concentrations in these sands seem to be related to the geomorphology

* Published by permission of the Atomic Energy Commission.

of river development and to the general structure and stratigraphy of the drainage basin. The total heavy-mineral concentrate and the percentage of hornblende, ilmenite, and monazite provide differentiating criteria for correlation with recognized source areas. The distribution of river sediments along the beach is controlled by a predominantly southwestward littoral drift.

Monazite concentrations of commercial grade are found in surficial sediments of the coastal plain, although areally extensive deposits are unlikely or at least not indicated to date. From its original source, generally considered as the saprolite of granitic intrusives (including quartz monzonites and pegmatites), the monazite has been redeposited as fluviatile placers in the piedmont. In the coastal plain, fluviatile and beach placers have been identified in basal sands of the Tuscaloosa (Cretaceous) and lower Tertiary formations and in stream deposits of Pleistocene to Recent age. In several areas the formational unit is not distinguishable, and the placer may cross formational and time lines.

Whereas the placer monazite is apparently distributed throughout sediments having a wide stratigraphic range, its geographic and physiographic occurrence is confined to a fairly narrow zone paralleling the Fall Line, mostly within the outcrop and overlap areas of the Tuscaloosa and lower Tertiary formations.

METASEDIMENTARY ROCKS IN STOKES, SURRY, YADKIN, AND FORSYTH COUNTIES, NORTH CAROLINA

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Metasedimentary rocks of unknown age, composed of quartzite and quartz-mica schist having a northeast strike and a low but varying dip, form the Sauratown Mountains in Stokes and Surry counties, and extend southwest into Yadkin and Forsyth counties, North Carolina. The quartzite and schist unit is surrounded by a mica gneiss unit of Precambrian (?) age which strikes northeast. West of the quartzite and schist unit, these rocks dip more than 45° NW., whereas east of the quartzite and schist unit they dip 25°–35° SE. Debris from the mountains has covered the slopes, and the relationships of the quartzite and schist unit to the mica gneiss unit are unknown. Along the eastern side of the quartzite and schist unit the mica gneiss unit contains, in addition to gneiss and schist, varying amounts of quartzite. Lenses of limestone occur in the quartzite and schist and in the mica gneiss to the east.

Recently, several old limestone pits in the two areas were examined. The base of the limestone is not exposed in any of the pits, but the top of the limestone is overlain with quartzite of varying thickness which grades upward into quartz-mica schist. The occurrence of quartzite and limestone in both the quartzite and schist unit and the mica gneiss unit presents an interesting problem as to the extent, relationships and ages of the two units.

STRUCTURAL FEATURES OF THE ANTHRACITE REGION OF PENNSYLVANIA

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Geologic mapping and mine data show that the anthracite fields of eastern Pennsylvania are located in the most deeply depressed parts of four complexly deformed arcuate synclinoria, separated by three less complexly deformed arcuate anticlinoria. Each field contains (1) en echelon folds whose lengths range from a few inches to more than 10 miles and whose amplitudes range from a few inches to several miles; (2) low- to high-angle folded thrust faults whose slips range from a few inches to about 1 mile; (3) high-angle thrust faults, generally inclined to the south, whose slips range from a few feet to several hundred feet; and (4) associated structural features, including tear faults, shear zones, joints, and drag folds. These structural features developed after

the deposition of the coal-bearing rocks of Middle Pennsylvanian age and before the deposition of the Triassic red beds that are preserved 20–25 miles south of the anthracite region.

The probable sequence of geologic events resulting in the present structural complex is (1) low-angle thrust faulting and imbrication accompanied by regional warping; (2) close folding and thrust faulting; (3) thrust faulting, tear faulting, and folding. These three types of structural features may have resulted from three orogenic pulsations or from continuous deformation that advanced progressively to the northwest across the region.

GRAVITY STUDIES IN THE DURHAM–SANFORD TRIASSIC BASIN OF NORTH CAROLINA

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Approximately 1300 gravity stations have been established in the Durham–Sanford Triassic Basin of North Carolina in 1958. Enough stations were located outside the basin to assure removal of regional trends. Surface geology may be correlated with gravity profiles. In some areas, profiles constructed from simple Bouguer values can be used to locate Triassic–pre-Triassic contacts; in other cases contacts are not so clearly delineated by gravity data. Although more data and calculations are necessary for complete conclusions, some preliminary interpretations concerning the geology and gravity field relations of the basin can be offered at this time.

MINERAL ASSEMBLAGES OF SOME NORTH CAROLINA PYROPHYLLITE DEPOSITS

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Samples of pyrophyllite deposits and associated country rocks, from Hillsboro, Staley, Robbins, and Glendon, in the "slate belt" of North Carolina, were studied by X-ray diffraction methods. Within the system Al_2O_3-SiO_2-H_2O, the most common mineral assemblages found are quartz-kaolinite-pyrophyllite, and its one- and two-phase subassemblages. The Hillsboro deposit also carries the andalusite-kaolinite-pyrophyllite-quartz assemblage and its subassemblages. At Staley, the andalusite-pyrophyllite-quartz and pyrophyllite-diaspore assemblages also exist.

Pyrophyllite-diaspore and kaolinite-andalusite form mutually incompatible mineral pairs. Differences must have existed in the physical conditions of metamorphism for the Staley and the Hillsboro deposits.

The andalusite-pyrophyllite-kaolinite-quartz assemblage is probably out of chemical equilibrium. In fact, textural relations suggest that anadalusite is generally a relict mineral in these deposits. The prevalence of three-phase assemblages in this system suggests that during the formation of the pyrophyllite deposits H_2O may have behaved as an inert component. Alternatively, if H_2O is taken as a mobile component, then these must represent metastable assemblages; the nature of the two-phase assemblages then shows the existence of gradients of chemical activity for H_2O.

Other minerals, not part of the Al_2O_3-SiO_2-H_2O system, are muscovite, chloritoid, chlorite, hematite, pyrite, fluorite, and possibly montmorillonite. The chloritoid-chlorite-pyrophyllite and chloritoid-chlorite-kaolinite assemblages are common in the country rocks. Paragonite is absent, indicating that during the formation of the deposits the chemical activity of Na_2O had very low values.

ABSTRACTS OF PAPERS SUBMITTED FOR THE MEETING IN MISSOULA, MONTANA, MAY 14–17, 1959

ROCKY MOUNTAIN SECTION (GSA)

SCAPOLIZATION OF A BELT SERIES ARGILLITE

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A spotted purple argillite within the Wallace formation of the Belt series contains small white spheres of a scapolite-group mineral disseminated throughout its groundmass. The scapolite forms almost perfect spheres approximately 2 mm in diameter. Other than the scapolite, the individual mineralogical components of the argillite are not megascopically discernible.

Under the microscope the argillite appears to be composed essentially of equigranular, but fine-textured, quartz, biotite, and sericite, with traces of tourmaline. The spherical metacrysts appear as almost perfect and distinct discs. Some of these metacrysts show zonation under crossed nicols. Their composition as determined by oil-immersion methods most closely approaches that of the scapolite mineral dipyre.

Although the dipyre molecule contains both chlorine and sodium, with the possibility that chlorine was introduced into the argillite under the mechanism of gaseous pneumatolysis, evidence for the presence of sodium in the form of soda feldspar is absent.

The evidence of the genetics for the scapolization of this argillite is not conclusive. It is hoped that a possibility exists whereby this unit with its unusual characteristics of scapolization may eventually be used as a correlation unit.

GENESIS OF ANORTHOSITE BODIES WITHIN THE METAMORPHIC ROCKS OF THE BITTERROOT RANGE, MONTANA

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Several small (*ca.* 1 km²) anorthosite (andesinite) bodies are well exposed in Bass Creek Canyon, Montana. The Bitterroot Range is composed of rocks of the border facies of the Idaho batholith. The anorthosite bodies are virtually monomineralic and are contained in sillimanite-bearing, quartzofeldspathic gneisses of high-grade amphibolite facies. The anorthosite bodies are thought to have had a metasomatic origin. Lack of contact metamorphism rules out the exceptionally high temperatures necessary for intrusion as a melt; injection as a crystal mush is precluded by lack of protoclastic texture. A well-foliated, concordant, border zone precludes the possibility of recrystallization subsequent to intrusion. The lack of structural deformation of the overlying rocks together with other structural relationships suggests origin *in situ*.

"Solution channels" rich in chlorite and biotite and a volcanic vent in the vicinity suggest that fluid material may have had access to the surface. Disequilibrium conditions indicated by strong zoning and wide compositional range of the plagioclase in the border zone may be a result of repeated removal of fluid phases.

The following relationships are characteristic of the sillimanite zone and suggest metamorphism at relatively shallow depth accompanied by large-scale shearing that partially controlled the mineralogy: (1) a rapid transition from quartzites and argillites to high-grade rocks of the amphibolite facies together with a diminishing of cataclastic effects in the same direction, (2) the restriction of sillimanite to, and alignment along, *S* surfaces, (3) the paucity of almandine garnet.

IRON-BEARING ROCKS OF THE ATLANTIC MINING DISTRICT, WYOMING —A PROGRESS REPORT

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The Atlantic mining district includes 220 square miles of Precambrian metasedimentary and metavolcanic rocks in the south part of the Wind River Range, Fremont County, Wyoming. It is known chiefly as a gold-mining district, but iron deposits of significant economic potential are being developed in the northeast part.

The iron-bearing rocks, which are sedimentary in origin, form the middle part of a stratigraphic sequence; they are underlain by quartzose schist and quartzite and overlain by schist and metavolcanic rocks.

The rocks are disposed in a tight northeast-striking syncline which is cut by abundant diagonal and transverse faults. Most diagonal faults are marked by sheared mafic dikes. The original folding and the emplacement of the dikes probably antedate the intrusion of the adjacent granite in the Wind River Range, but the faulting is post-granite in age.

The iron formation (taconite) where unfaulted is about 150 feet thick, but it is greatly thickened by diagonal faulting at some places. It consists of thin layers dominantly of quartz alternating with layers in which magnetite is dominant; grunerite is a common but minor accessory mineral. The content of magnetite is 40 to 50 per cent. Reserves of magnetic taconite may exceed several hundred million tons.

DESERT FLOODING AND DEBRIS-FLOW DEPOSITION

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An investigation of gradational processes active in and around a high desert range was made in the White Mountains, California and Nevada, in connection with a U. S. Army Quartermaster Corps contract study of desert flooding. Particular attention was given to flooding and debris-flow deposition on alluvial fans. Examination of the canyons and fans reveals that under existing climatic conditions the debris flow (or rubble flow) accompanying the large cloudburst flood is a major agent of morphologic change. By such flows, trunk canyons are cleared of unconsolidated material, and significant additions are made to the volumes of contiguous alluvial fans.

Surface morphology and internal structure of the White Mountain fans indicate they have been built by a superposition of numerous debris flows. The evidence thus suggests that a climate similar to that of the present has prevailed in the area during recent geologic time. Although Pleistocene glaciers were active in higher parts of the range, gradational processes on the flanks and fans were essentially as they are today.

The gradational history of the typical White Mountain canyon and associated alluvial fan follows a cyclical pattern and shows: (1) a long period during which debris accumulates on the canyon floor; (2) a major flood and debris flow by which unconsolidated material is carried out of the mountains to the fan surface; (3) another long inactive period, eventually followed by the inevitable cloudburst flood and rubble flow.

GOLDEN FAULT—AN UNDERTHRUST?

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The Golden fault is on the eastern margin of the Front Range, Colorado. It is one of several thrust faults that indicate east–west compression and an apparent wedge structure for *parts* of the range. The range is actually a "welt" of Laramide age.

The sinuous fault trace is in the sedimentary beds of the foothills. Older beds overlie younger;

a maximum of 11,000 feet of strata is faulted out. A narrow belt of steep to overturned upper Cretaceous beds parallels the outer side of the fault trace and closely approaches Precambrian near Golden.

The fault is not a thrust of rigid Precambrian rocks over yielding sedimentary beds. Thrusting from the east through soft Cretaceous shales to produce the westward embayment near Golden is improbable. Near-vertical uplift at the range border tilted about 12,000 feet of sediments to a dip of about 35° E. Compression in the lower curve of the foothills monocline developed shearing, most intense in the upper beds, beginning at the surface and extending down and westward. The Golden fault is a strongly warped shear, nearly vertical at Golden, nearly flat in soft Cretaceous shales elsewhere.

Development of the shear was probably concomitant with the flexing of the foothills strata. Vertical shearing near Golden was localized by resistance of vertical, east–west rigid quartzites in the Precambrian to north–south folding.

PEGMATITES OF STORM MOUNTAIN AREA, LARIMER COUNTY, COLORADO*

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Some Precambrian granitic pegmatites on the southeast, south, and southwest slopes of Storm Mountain in northern Colorado were explored and mapped geologically and mineralogically by plane table in 1955–1957. Some were exploited for beryl, uraniferous minerals, and other pegmatite minerals in 1956–1957.

The area is in T. 6 N., Rs. 71 and 72 W., Roosevelt National Forest, between the Crystal Mountain pegmatite mining district on the north and the Hyatt beryl pegmatite mine area on the south. The extremely rugged topography, inaccessibility, and bulk of the leucocratic aplite-pegmatite intrusives discouraged exploration until the completion of a Company access road in 1957.

Almost innumerable pegmatites invade Precambrian gneiss, schist, and granite within the great tilted fault block of Storm Mountain. At the northeast, the fault-line scarp is more than 10,000 feet above sea level, rises some 1500 feet above the east slope of the Front Range, and trends north west. The pegmatites are genetically related to the Mount Olympus granite. Beryl-bearing pegmatites north of Cedar Park stem directly from granite exposures.

Concordant and discordant lenses, tabular sheets, and spilite-hooded pods range from a few feet long and thick to massive complex bodies 200–600 feet long and deep and 30 to 300 feet across. Internally many are granitic to graphic and contain plumes of quartz-muscovite and clots of coarse pegmatite. Others are coarsely layered to delicately ribboned transverse to the strike and dip of the deposit. A few are well zoned concentrically. Beryl is prismatic to granular and massive.

NEW EVIDENCE IN THE STRUCTURAL HISTORY OF THE TETON RANGE, WYOMING

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The Precambrian rocks of the Teton Mountains are a complex of intruded gneisses and schists similar to the older Precambrian rocks of other areas. They are overlain unconformably by Paleozoic sediments, faulted, uplifted, deeply eroded and swept clean by glaciers, making this an unusual opportunity for a three-dimensional study.

Structural deformation is so intricate and so extreme that, before sensible geologic mapping can be done, the broad structural pattern must be delineated. The most obvious portion of this pattern relates to post-Precambrian deformation—mainly Laramide and later.

The area studied lies between Death Canyon on the south and Cascade Canyon on the north. Other than the Teton fault which borders the whole range on the east, the main structural linea-

*By permission of National Beryl and Mining Corp., Estes Park, Colo.

ment in this area is Buck Mountain fault, previously described as a "normal" or "tensional" or "block" fault. Careful remapping reveals it to be a large eastward-dipping high-angle thrust fault along which the main eastern block of the Teton Mountains has risen to produce the highest peaks of the range. The thrust was relieved mainly by overlapping movement of three fairly well defined imbricate sheets and to a lesser extent by en echelon strike-slip movements.

Some of these movements have been favored by previously existing Precambrian structures—some may even be reactivated Precambrian faults. Shear stresses have produced retrograde metamorphism of the Precambrian rocks making biotite schist out of the hornblendite and granitic gneisses.

The relationship of Buck Mountain fault to the smaller faults previously described by this writer and others is discussed, and in this light the structural history of the Teton Range is reappraised.

PRECAMBRIAN–CAMBRIAN UNCONFORMITY IN NORTHWESTERN MONTANA AND NORTHERN IDAHO

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Mapping near Superior, Montana, has disclosed additional evidence that the long-recognized unconformity between sedimentary rocks of Precambrian and early Middle Cambrian ages represents a major interval of geologic time. The Flathead quartzite (Middle Cambrian) rests on rocks of the Missoula group (Precambrian Belt series) at several places in the mapped area. At each locality the Cambrian rocks appear conformable on the Precambrian rocks, but within the area of detailed study it is evident that the Flathead quartzite rests on different parts of the Belt series at different places.

On a regional scale, correlative Cambrian rocks are in contact with progressively older units within the Belt series at several localities from Missoula, Montana, to Pend Oreille Lake, Idaho. The Wallace formation and its equivalent, the Newland formation, of the Belt series are present throughout the region and are used as a plane to which the younger stratigraphic units and the unconformity may be referred. The evidence suggests that a long period of erosion preceded the deposition of the Flathead quartzite and that as much as 7000 feet of Belt series sediments may have been eroded from the Pend Oreille area before the deposition of Cambrian sediments.

An age determination of about 1200 million years for a uraninite vein that cuts folded metasedimentary rocks of the Belt series in the Coeur d'Alene district, Idaho, emphasizes the great time interval between the Belt series and the Cambrian rocks.

ADDITIONAL EVIDENCE OF GLACIAL LAKE MUSSELSHELL, MONTANA

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Alden (1932, p. 81) theorized from the topographic position of a granite erratic in sec. 4, T. 13 N., R. 34 E., that glacial Lake Musselshell spilled over the divide between the Yellowstone and the Musselshell rivers and drained into the Yellowstone River a few miles west of Forsyth, Montana. Discovery by Colton of additional erratics approximately 22 miles north of Ingomar, Montana, and by Howard Smith in an area 12 miles northeast of Melstone, Montana, supports this conclusion. Three other possible spillways are suggested as a result of the study of high-altitude aerial photographs. One of these is 2 miles west of Sumatra, Montana; another is in sec. 34, T. 12 N., R. 34 E.; the third is in sec. 19, T. 13 N., R. 34 E. All the erratics that have been found are believed to be below an altitude of 3150 feet which apparently marks the maximum level of glacial Lake Musselshell. Recently published (1:250,000 scale) topographic maps make it possible to plot the approximate outline of this glacial lake.

GEOLOGY AND ECONOMICS OF GROUND WATER IN MONTANA

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Ground water is an important mineral resource in Montana and is of great importance to the present economy and the future industrial development of the State. Ground-water use is increasing rapidly in direct ratio to the availability of low-cost energy for pumping and to increasing land values.

Present studies indicate that the ground-water resource is almost untapped over most of Montana, but danger of overuse and depletion is present in some areas. The State is divided into three broad geographic divisions wherein ground-water occurrence is determined by conditions of topography, climate, and geology.

Western Montana is characterized by high mountainous areas which collect relatively heavy precipitation for release to storage in the thick alluvial fill of intermontane valleys. This division is comparatively rich in ground-water resources under water-table conditions. Bedrock aquifers are unimportant.

Central Montana consists of high plains and isolated mountain uplifts. The climate is semiarid except in the high mountains, and most ground-water developments are in the major river valleys. Bedrock aquifers are being increasingly developed, and several important artesian basins have an excellent potential. Many small wells draw water from preglacial terrace gravels and glacial deposits.

Eastern Montana consists of rolling and deeply dissected plains. The average climate is semiarid, and precipitation is erratic. Large supplies of ground water are developed in the major river valleys, but water for the important stock-raising industry must be withdrawn from bedrock sources.

GEOLOGY OF THE WEST TINTIC RANGE AND VICINITY, JUAB AND TOOELE COUNTIES, UTAH

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The West Tintic area is in the eastern portion of Juab and Tooele counties, Utah, approximately 80 miles southwest of Salt Lake City, and includes a portion of the eastern and southern flanks of the Sheeprock Mountains in addition to the West Tintic Range. The range is basically an elongate, north-trending, westward-overturned anticline complicated by thrust imbrications and largely obscured by Tertiary extrusives and Quaternary (?) gravels.

Allochthonous Precambrian rocks constitute most of the Sheeprock portion of the area and occur as Laramide thrust remnants in the more easterly West Tintic Range. Tillites, varved and unvarved phyllites, conglomerates, and quartzites represent deposition in rapidly changing environments during latest (?) Precambrian.

Predominantly carbonate strata of all the Paleozoic periods, except the Permian, are present, although some units or portions thereof were not recognized because of complex faulting and alteration. The Victoria quartzite and thick (1500 feet) clastic sediments of the Chiulos shale member of the Great Blue limestone indicate crustal unrest in Late Devonian and Late Mississippian. A major unconformity occurs at the base of the Madison limestone where it rests on Middle Devonian Simonson dolomite in the West Tintic Range.

Paleocene (?) conglomerates rest unconformably on Paleozoic strata and are unconformably overlain by Tertiary extrusives in the central West Tintic Range. Extrusives rest on eroded granite in the southern portion and are interbedded with Eocene Green River strata in the central portion. Strata of the Salt Lake group overlap the southeastern flanks of the range where they are largely covered by Pleistocene(?) pediment gravels.

STRUCTURE OF THE NORTH PART OF THE GRAVELLY RANGE, MADISON COUNTY, MONTANA

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The northern part of the Gravelly Range, shown as a major syncline on older maps, is cut by a major northwest-dipping thrust fault. Considerable displacement on this fault is indicated by the fact that 600 feet of Mississippian rocks (Big Snowy group) and 700 feet of Cambrian rocks (Park, Pilgrim, and Red Lion formations) present on the northwest side are absent on the southeast.

The fault truncates northwest-trending folds and minor thrust faults in the Paleozoic and Mesozoic rocks of the Gravelly and Greenhorn ranges. In the Greenhorn and Snowcrest ranges a parallel thrust west of the first brings basement gneisses over Paleozoic rocks. The faults originate in the basement, and displacement on them is probably several miles. They cut Upper Cretaceous rocks and are overlain by gravels and olivine basalt of middle or late Tertiary age.

The fault zone trends N. 25°–30° E. roughly parallel to northeast-trending fault systems in the northwest Tobacco Root Mountains, in the Pioneer Mountains northwest of Dillon, and in the Lombard thrust zone northeast of Three Forks. It is suggested that these structures are younger than the northwest-trending folds of the region and are related to the emplacement of the Boulder batholith.

The east side of the Gravelly Range is marked by steep northwest-trending faults with displacement of 100–500 feet associated with the downfaulting of the Madison Valley in late Tertiary or early Quaternary time.

MULTIPLE GLACIATION AND HIGH-LEVEL TILL DEPOSITS IN SOUTHWESTERN MONTANA

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During the past 4 years detailed geologic mapping in the Gallatin and Madison ranges of southwestern Montana has brought to light a considerable amount of evidence which suggests much more extensive glaciation in this region than has been generally recognized. We may now expand the picture presented for this area by Alden in his recent (1953) regional reconnaissance of glaciation in western Montana.

Certainly two, and possibly three, stages of glaciation can be demonstrated in the Upper Gallatin Valley region with evidence now at hand. The earlier stage of glaciation was tremendously more extensive than the most recent ice advance. High-level till deposits (up to 9525 feet elevation) cap stream divides and in some places are 4 miles downstream from the younger terminal moraines. The writer suggests that virtually all the Upper Gallatin Valley drainage basin was glaciated during earlier ice advances, and that the ice during its greatest expansion was essentially continuous from the crest of the Madison Range on the west, eastward across the Gallatin Range to the Yellowstone-Absaroka ice fields. The northern limit has not yet been defined but presumably was near the mouth of Spanish Creek where it joins the Gallatin River. To the south evidence suggests continuity with vast ice fields of northwestern Yellowstone Park and the Henrys Lake Mountains. The age of the most extensive ice advance is still uncertain; welded rhyolitic tuffs (Pliocene?) appear to have been glaciated and are overlain in places by the highest till deposits.

POTASSIUM-ARGON DATING IN WESTERN MONTANA

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Potassium-argon dates on Archean rocks of western Montana indicate at least two major periods of tectonic activity. A date on amphibole in an amphibolite from the Cooke City highway (Bear-

tooth Plateau) indicates an age of 2540 million years. This correlates very well with potassium-argon dates on the area reported by other laboratories. A feldspar date, using a total decay contact of .5277 x 10^{-9}/year and branching ratio of .085, from a pink granite near Niehart, Montana, gave an age of 1690 million years (average of two runs). A biotite date from a biotite gneiss 6 miles east of Norris, Montana, also gave a date of 1690 million years.

The K-A age of biotite from a pegmatite located in Bass Creek in the Bitterroot Mountains is 42.6 million years. This date indicates that metamorphic activity in the Bitterroot Mountains continued somewhat later than had been previously suspected.

The decay constants, except in the case of the feldspar, are those quoted by Wetheral *et al.* (total = .5277 x 10^{-9}/year; branching ratio = .119).

A^{40}/K^{40} AGE DETERMINATIONS OF THE NORTH END OF PIKES PEAK BATHOLITH, JEFFERSON, DOUGLAS, AND PARK COUNTIES, COLORADO

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A^{40}/K^{40} ages on biotite from samples of granite and granodiorite collected 3 miles and 5 miles respectively, inward from the granite–Idaho Springs gneiss wall-rock contact give ages in agreement with probable sequential development of batholithic rock zones so far mapped.

Granite of the outer zone is 1.08 billion years, and granodiorite is 1.05 billion years old. Repeat runs on the argon indicate the checks are good, so that it does appear the granite may be older than the granodiorite. Uncertainty in constants for K-A is of the order of magnitude as the apparent age difference between the two samples so that definite establishment of an age difference is hazardous.

Distribution, quantity, and types of primary fracture systems either devoid of or filled with alaskite, pegmatite, and/or aplite indicate that outer-zone rocks should be older and have crystallized before the granodiorite toward the interior of the batholith. In the outer zone, half an inch to 4-inch veins of allanite, steeply dipping and genetically related to cooling and crystallization of the granite, are offset by gently dipping marginal fissures. Reverse faulting occurred along some of these marginal fissures prior to their occupancy by pegmatite and/or aplite. Distribution and abundance of these pegmatite and/or aplite-filled marginal fissures within a 1-mile wide border adjacent to the metamorphic wall rocks appear to confirm and lend corroborative significance to the apparent age difference between the two rocks.

PETROGRAPHY OF THE BROWNE LAKE AREA ROCKS, BEAVERHEAD COUNTY, MONTANA

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Granodiorite in the western part of the area lies concordantly against marmoritized magnesian Madison limestone. Samples from White Elephant Mine south to Ivanho Mine show an increase in sphene. Hornblendic banding occurs up to 5 feet into the granodiorite from the granite–marble contact.

Typical tactite skarn with scheelite and chalcopyrite have been developed at Browne Lake. Alternating bands of magnesian-lime silicates, fine-grained hornfels, and thick garnet layers occur. Locally these show small concentric zonary structures developed with a core and successive concentric shells. Core material is calcite with succeeding rims of garnet-diopside, epidote-quartz, and biotite-quartz-hornblende.

Buchite has been developed on Beal's Mountain klippe in Quadrant quartzite. A 4-foot dike of olivine-augite basalt intruded along a high-angle right-lateral fault. Heat of intrusion has produced corroded grains of quartz with patches of pale-brown glass enclosing length-slow fibers of (?) mullite. Flow occurred within a ¼-inch to 1-inch thick border of fused quartz next to the olivine basalt.

Actual melting of quartzitic material seems to indicate that the dike rock came up without large amounts of phenocrysts thus insuring greater amounts of superheat possible for actual fusion.

Dike rocks in the area probably served as source fissures for volcanic flows present. Four individual dikes averaging 2 miles in length and 1–10 feet in thickness are olivine basalts with iddingsite. Pyroxenes are augite of slightly varying optic angle. Textures are intergranular to intersertal. Volcanic flows aggregate 460 feet in thickness, and from the base upward they vary from olivine basalt to augite andesite to olivine basalt.

FABRIC STUDIES OF IDAHO SPRINGS GNEISS, TURKEY CREEK CANYON, JEFFERSON COUNTY, COLORADO

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Fabric diagrams of foliation, linear structures, joints, faults, and pegmatite and/or aplite dikes have so far revealed a single major Precambrian fabric trend of N. 30°W. ± 10°. Greater development of cross warps, L_w, within quartzo-feldspathic units than within less competent approximate amphibolitic units produced girdle-polar patterns. These cross warps originated from torsional deformation contemporaneous with regional folding all probably in late Precambrian time. Left-lateral faults prevail and have severely drag-folded metamorphic units. Hornblende gabbro intrudes concordantly along minor folds.

Linear structural elements are minor fold axes, L_A, L_B; warps, L_w; drag folds, L_{df}; crinkles, L_{cr}; sillimanite, L_s; hornblende, L_h. Plastic overfolding that has developed into axial-plane thrust faulting within quartzo-feldspathic units appears to be accompanied by development of pegmatites and/or aplites along the shear planes or zones. Granitic, pegmatitic, and aplitic material generated within (?) the quartzo-feldspathic gneisses intruded less competently behaving amphibolitic units partly or wholly engulfing blocklike portions of these.

Fabric diagrams and tables show the more persistent trends.

Foliation Trends (S surfaces)	*Lineation Trends (L_A, L_B, L_w, L_{df}, L_{cr}, L_s, L_h)*
S_1 N. 78°E., 32° SE. to N. 3° W., 33° SW.; girdle	(1) 16° plunge N. 45°E.; polar
S_2 N. 2°E., 17°SE. to N 12°W., 46°NE.; girdle	(2) 76° plunge N. 53°W.; polar
S_3 N. 58°W., 48°NE.; polar	(3) 89° plunge S. 53°E.; polar
S_4 N. 46°W., 76°SW. to N. 16°W., 61°SW.; girdle	(4) 20° plunge S. 83°W. to 26° plunge, S. 74°E.; girdle
S_5 N. 12°W., 46°NE.; polar	
S_6 N. 84°E., 72°NW. to N. 46°E., 62°NW.; girdle	(5) 70° plunge N.52°E. to 0° plunge N.26°E.; girdle

Joint Trends	*Fault Trends*	*Pegmatite and/or Aplite Dikes*
J_1 N. 77°W., 82°SW.; polar	F_1 N. 85°E., 38°SE.; polar	PA_1 N. 41°W., 70°NE.; girdle-polar
J_2 N. 35°W., 63°SW.; polar	F_2 N. 28°W., 90°; polar	PA_2 N. 78°E., 43°SE.; polar
J_3 N. 17°W., 52°NE.; polar	F_3 N. 15°E., 90°; polar	PA_3 N. 86°E., 70°SE. to N. 33°W., 90°: girdle
J_4 N. 56°W., 80°SW. to N. 33°E., 75° NW.; girdle	F_4 N. 35°E., 90°; polar	

CAMBRIAN STRATIGRAPHY IN THE GARNET RANGE OF WESTERN MONTANA

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Previously undifferentiated Cambrian strata of the Garnet Range are correlated with the Philipsburg area section chiefly on the basis of lithology.

The Flathead quartzite resembles much of the underlying Missoula group but rests on it above a slight angular unconformity, hematitic staining is more common, and the Flathead typically has small pebbles scattered through the quartzite matrix.

A basal 20-foot greenish-gray shale member of the overlying Silver Hill formation has yielded a conchostracan, a hyolithid, two brachiopod species, and five trilobite species, all previously described. New forms include *Hyolithes*, n.sp., two new species of the sponge *Tuponia*, and a problematical fossil, possibly a bryozoan. The middle limestone unit, with argillaceous laminae, is approximately 250 feet thick and contains *Girvanella*, n.sp. The upper 20-foot illitic shale member contains three species of brachiopods and a hyolithid, all previously described. The fossils from the Silver Hill indicate an early Middle Cambrian age (*Albertella* zone).

The Silver Hill grades upward into the Hasmark formation, approximately 1200 feet of white, yellow, and light-gray dolomite. A single trilobite, *Glyphaspis robustus* Deiss, suggests a late Middle Cambrian age for at least part of the Hasmark formation.

The overlying Red Lion formation, 345 feet of limestone with red or yellow argillaceous laminae, has been dated previously as Franconian (middle Late Cambrian). A disconformable relationship possibly exists between the Red Lion and the Hasmark, as well as a definite disconformity between the Red Lion and the overlying Maywood formation of Devonian age.

GEOLOGY AND GROUND-WATER RESOURCES OF THE BITTERROOT VALLEY, RAVALLI COUNTY, MONTANA

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In 1955 a study of the geology and ground-water resources of the Bitterroot Valley was started by the U. S. Geological Survey in co-operation with the Montana Bureau of Mines and Geology. The area studied is about 50 miles long extending northward from Darby to the Ravalli County line.

The Bitterroot Valley is a broad, north–south trending, structural trough, lying between the rugged Bitterroot Mountains on the west and the more subdued Sapphire Mountains on the east. The steep, straight eastern front of the Bitterroot Mountains and the terraces which slope gently downward from the mountains to the broad flood plain of the Bitterroot River are the most prominent physiographic features of the area. The Bitterroot Valley has a fill of more than 1700 feet of Cenozoic sediments, largely derived from the weathering and erosion of adjacent areas. Most of the exposed Tertiary sediments are Pliocene, but the older ones may be Oligocene. Tertiary sediments are fine-grained and yield little water to wells.

Pleistocene and Recent terrace deposits and alluvium are the most important aquifers in the Bitterroot Valley. In general, these sediments are of larger grain size and are better sorted and thus have higher transmissibility and storage coefficients than do the Tertiary sediments. About 165,000 acre feet of ground water is available for development in the Bitterroot Valley each year.

PALEOECOLOGY OF AN EARLY OLIGOCENE (CHADRON) BIOTA FROM DOUGLASS CREEK BASIN, MONTANA

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Douglass Creek Basin lies west of the Continental Divide in the Northern Rocky Mountains physiographic province. Numerous minor environmental differences exist between the Douglass Creek area and the Pipestone Springs and Canyon Ferry localities east of the Divide. However, in the nineteenth century the three areas had identical mammalian species representation, although not equally dense populations. Parts of an early Oligocene (Chadron) biota have been collected in Douglass Creek Basin. Duplication at Pipestone Springs and Canyon Ferry of all but one of the mammalian species suggests that the three ancient ecosystems were similar to each other in much the same way as the nineteenth century systems.

The Chadron sediments and biota of Douglass Creek Basin are indicative of a moist temperate

climate with seasonal variations. Sediment size and distribution suggest that the cross-valley relief was no greater than, if as great as, it is now. The Chadron fish and invertebrate faunas show that a shallow, hard-water lake existed in the area. The Chadron flora included a lake-border association and an upland coniferous forest. Although the ancient biota doubtless included many species not represented in the fossil collections, most of the mammalian species are probably represented in the combined Douglass Creek, Pipestone Springs, and Canyon Ferry fossil assemblages. If this is so, the number of mammalian species was about the same as in the modern ecosystem.

BORDER-ZONE PETROLOGY OF THE IDAHO BATHOLITH IN VICINITY OF LOLO HOT SPRINGS, MONTANA

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The area is located along the Lewis and Clark Highway about 6 miles northeast of Lolo Pass and covers 20 square miles at the contact of the Idaho batholith with the Precambrian limestones, quartzites, and argillites of middle and lower Belt series.

A dioritic body ranging in composition from diorite to quartz diorite is found in the southeastern part of the area. Lower Belt quartzites and argillites surrounding the diorite were metamorphosed to an augite-plagioclase-quartz hornfels. The overlying Wallace limestone was metamorphosed to diopsidic augite-scapolite hornfels near the contact and tremolite-plagioclase-quartz amphibolite away from the contact. The diorite, metamorphic rocks, and associated sediments are cut by dikes of fine-grained diorite, lamprophyre, hornblendite, and quartz diorite porphyry.

A later quartz monzonite intrusion lies to the west and is separated from the diorite by the hornfels zone surrounding the diorite. Within the interior of the quartz monzonite are many aplite-pegmatite bodies of varying texture, shape, and size. Two sets of dikes of quartz monzonite porphyry, one set of quartz porphyry, and a large granite porphyry dike cut the sediments.

Two high-angle faults of northeast trend with large displacement have brought lower Belt quartzites and argillites into contact with middle Belt Wallace limestone. One is known to cut the quartz monzonite.

POSTGLACIAL MOVEMENT ALONG NORMAL FAULTS IN AND ADJACENT TO YELLOWSTONE NATIONAL PARK, WYOMING

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Normal faults, some with throw exceeding 200 feet, offset a bedrock surface scoured by the Buffalo piedmont glacier (middle or late Pleistocene) in several places in Yellowstone National Park and adjacent areas. Seismic activity suggests that movement is continuing along some of these faults.

Postglacial movement has occurred along more than 50 faults on the Mirror Plateau, 15 miles northeast of Yellowstone Lake. Faults trend northwest. One fault is more than 6 miles long; several have displacements of 200 to 400 feet. The northeast blocks of most are downdropped. Some grabens and horsts occur. Rocks displaced are volcanic or pyroclastic and range in age from Eocene to Pliocene. Buffalo ice moved southwest or south from the Beartooth and Absaroka ranges, nearly at right angles to the faults. Hence, drainage in many ice-scoured valleys was disrupted by subsequent faulting, and small lakes (such as Mirror Lake) formed on downthrown blocks. Recent thermal activity occurs along some of these faults.

Fifty miles southwest of Mirror Plateau, postglacial north-trending faults, constituting the northern terminus of the Teton fault zone, cross the Yellowstone Park boundary 5 miles west of the South Entrance. Buffalo ice moving southwestward scoured the surface of middle (?) Pliocene rhyolitic welded tuff. This surface was subsequently displaced by these normal faults. The east blocks were downdropped. Maximum displacement exceeds 200 feet. West-flowing drainage was disrupted, and Beula, Hering, and South Boundary lakes formed on the downthrown blocks.

STRUCTURES AND THE CAMBRIAN-BELTIAN CONTACT SOUTHWEST OF DRUMMOND, MONTANA

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Between the north boundary of the Philipsburg quadrangle and the Clark Fork River, Montana, Beltian and Lower and Middle Paleozoic sedimentary rocks occur in moderately folded and complexly faulted northwest-trending belts, segmented by east-northeast cross faults. The Beltian rocks are correlated with the Missoula group of Blackfoot Canyon, described by Clapp and Deiss.

Near Stone at the south end of the area only the lower part of the Hellgate formation and the underlying Newland formation are present. To the north, the McNamara formation appears on Cow Creek, and a mile farther north basal beds of the Garnet Range formation overlie the McNamara. North of the Clark Fork the entire Missoula group can be recognized.

Point diagrams of poles to bedding for the Paleozoic rocks of the area show a simple pattern indicative of moderate folding with small, generally southerly plunges. Similar diagrams for Beltian rocks reflect the same kind of folding, but the pattern is more complex. Major folds plunge generally northward at $\pm 20°$, and subsidiary cross folding is present. The Belt was strongly tilted, warped, and probably faulted prior to deposition of Cambrian sediments. A regional "high" existed in the Willow Creek area 5 miles southwest of Hall, and younger formations of the Missoula group appear successively beneath the Paleozoic rocks to the north of this "high". The Missoula group also thickens south of the "high", although individual formations have not yet been distinguished.

GEOLOGY OF THE NIMROD AREA, GRANITE COUNTY, MONTANA

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The Nimrod area is located in the southern part of the Garnet Range, 35 miles southeast of Missoula in Granite County, Montana. The area has rugged topography developed from a maturely dissected erosion surface of low relief. Precambrian to Recent sedimentary rocks (about 20,000 feet) are present. These include the Missoula group of sandstones, quartzites, and argillites, which accumulated in shallow seas. Paleozoic and Mesozoic rocks are mainly marine limestones with lesser amounts of dolomite, shale, siltstone, and quartzite.

Structurally, the northern half of the area is an asymmetrical, southeast-plunging syncline, and the southern half is a northwest–southeast trending thrust block of Precambrian and Cambrian rocks which moved northward during late Cretaceous time. A large high-angle normal (?) fault occurs in the southern portion of the thrust block parallel to the main thrust.

Intrusive rocks include a thick differentiated diabase sill and a small diabase dike, both of which were injected into Upper Beltian strata probably during major deformation of the region. Andesite porphyry, dacite porphyry, and olivine basalt were extruded during early and middle Tertiary time and covered much of the area.

A broad erosional surface of low relief developed during middle Tertiary time. Regional uplift during late Pliocene–Pleistocene time renewed erosional activity and formed the present maturely dissected topography.

RELATION OF UPWELLING MARINE WATERS TO PHOSPHORITE AND OIL

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Many marine phosphorites and important source beds of petroleum form where cold subsurface water, rich in P, N, and Si, wells upward. This water becomes saturated with phosphate as it approaches the surface and is warmed, and under special conditions it may also become saturated with carbonates and salines. The abundant organic growth made possible by the nutrient elements in the

water produces important accumulations of shells and skeletons, mainly of siliceous and phosphatic composition, and of carbonaceous matter. Sulfides and petroleum form under the reducing conditions that prevail where large amounts of carbonaceous matter are deposited.

The location of present-day areas of upwelling provides clues to the occurrence of phosphorite and oil, particularly in upper Mesozoic and Cenozoic rocks. Phosphatic sediments are found on the sea bottom in most of the areas of upwelling described by Mrs. M. Brongersma-Sanders (1957), and phosphatic sands, similar to those in Baja California, probably also occur in many of the adjacent coastal deposits. As the main ocean currents apparently have not shifted much since the Cretaceous, upwelling probably occurred long ago in or near many of the places where it is occurring now. Cretaceous and Tertiary rocks adjacent to some areas of upwelling do, in fact, contain phosphate and oil, and it is reasonable to suppose that phosphate and oil also may be found in unexplored rocks near other areas of upwelling.

METAMORPHOSED LAMPROPHYRE AND RELATED DIKES, NORTHERN SAWATCH RANGE, CENTRAL COLORADO

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Hundreds of metamorphosed Precambrian mafic dikes, typically 3–10 feet wide, form an elongate swarm in the northern Sawatch Range, Colorado. Most dikes parallel the trend of the swarm and are concordant with foliation in the host gneisses and granitic rocks, but some transect the foliation. The dike rocks consist of hornblende, biotite, andesine, quartz, and potassium feldspar in various proportions; the proportion of mafic minerals ranges from 40 to 80 per cent. Chemically the rocks are high in Fe, Mg, alkalies, Ba, and Sr and thus resemble lamprophyres such as minette, vogesite, and spessartite.

The original rocks have been almost completely reconstituted, but chilled borders are still evident in the outcrops, and relics of original plagioclase and pyroxene, and of original porphyritic texture, are visible under the microscope in some. Foliation and lineation within the dikes parallel the walls and are independent of structure in the wall rocks.

The dikes are closely related spatially to a belt of calc-silicate gneiss, and, as they resemble this gneiss in composition, the dikes may represent mobilized calc-silicate gneiss.

The dikes record almost the latest Precambrian event in the region. Relict features suggest they formed in a hypabyssal environment, and they are therefore much later than the plutonic granites and the regional metamorphism; yet the dikes themselves are metamorphosed, approximately to amphibolite facies. This recrystallization may reflect a late weak regional metamorphism, or, more likely, it was confined to the dikes and is a consequence of stress along them.

EFFECT OF WATER TEMPERATURE AND SALINITY ON SKELETAL MAGNESIUM AND STRONTIUM UPTAKE BY *DENDRASTER*

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Specimens of *Dendraster excentricus* were collected from 24 localities between Vancouver Island, British Columbia, and Santa Rosalia Bay, Baja California, in order to study the effect of water temperature and salinity on the concentration of skeletal magnesium and strontium. These tests were analyzed for magnesium by an X-ray-diffraction technique; for strontium by an X-ray-spectrographic technique. The calcium content was calculated assuming 100 per cent carbonate.

Changes in the amount of magnesium carbonate in the test material appear to be related to both water temperature and salinity. Specimens from waters of low salinity contain less magnesium carbonate than do specimens from normal-salinity waters of the same temperature. The mean magnesium carbonate content of normal salinity populations increases about 0.5 per cent above a range in temperature of 10°C. (mean temperature of the three warmest months). The strontium–calcium

ratio in sand-dollar tests decreases roughly with increasing temperature and appears unaffected by salinity changes.

Satisfactory evaluation of the numerous ecological factors that are involved in carbonate deposition is curtailed by the difficulty in obtaining precise environmental data for recent environments. For this reason, artificial laboratory growth studies may be of considerable aid in defining the various relationships more precisely.

DISTRIBUTION AND CHARACTERISTICS OF ASH FLOWS ASSOCIATED WITH THE CREEDE CALDERA, SAN JUAN MOUNTAINS, COLORADO

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Volcanic rocks directly related to the formation of the Creede caldera consist largely of ash flows deposited in two stages: a precaldera stage and a caldera-subsidence stage. Pumice deposited prior to the initial collapse of the caldera was produced by apparently continuous eruption of rhyolitic magma; this material has a maximum thickness exceeding 3500 feet and ranges from highly welded rock resembling fluidal rhyolite in the lower part to essentially nonwelded pumice breccia at the top.

Eruptions of rhyolitic magma during the caldera-subsidence stage deposited volcanic rocks on the rim and probably within the caldera. These rocks have a maximum aggregate thickness greater than 2500 feet. Early eruptions of this stage produced a unit of thin interlayered poorly welded pumice breccias and welded ash flows; later eruptions deposited thick sequences of highly welded ash flows. Over large areas, lava flows and minor nonwelded pyroclastic rocks constitute about 30 per cent of the rocks of this stage.

Welded quartz latitic ash flows more than 4000 feet thick are now exposed in the caldera core. These rocks may have been deposited concurrently with some rhyolitic ash flows of the caldera-subsidence stage, to which they bear a close resemblance. Other quartz latitic ash flows occur near the outer margin of the caldera rim and include deposits both older and younger than any of the rhyolitic ash flows.

Textural and structural similarities of some ash flows and lava flows suggest that minor changes in magmatic conditions may control the alternation of violent eruptions of ash flows with quiescent extrusion of lava.

KINEMATIC ANALYSIS FOR METAMORPHIC ROCKS IN THE UPPER SOUTH FORK OF THE CLEARWATER RIVER AREA, IDAHO

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Belt-equivalent(?) northwest-trending metamorphic rocks in this area contain four lineation sets that are assigned to four postulated metamorphic episodes, each of which produced a particular widespread variety of structure. The lineation sets (axes of small folds) are 15°–20° apart where two or more sets are exposed in the individual outcrop.

Small isoclinal folds, which reflect the oldest variety of large folds, have nearly parallel limbs (s_1), sharp hinges, amplitude much greater than wave length, and strong axial-plane foliation (s_2). Feldspathization occurred in this episode.

Small concentric folds reflect the next youngest large folds, in which axial-plane foliation (s_2) is folded and in which amplitude is about equal to wave length. Abundant thin granodioritic "sills," nonfolded to strongly folded in ptygmatic folds, and granodioritic axial-plane dikes, coincident with axial planes of many concentric folds (s_3), formed in this episode, probably by metamorphic differentiation. Although the complex deformation makes the orientation of axial planes of large folds difficult to ascertain, statistical analysis of axial planes of small concentric folds indicates that the large concentric folds were overturned to the southwest at about 45° prior to the third episode.

Fold patterns developed in the concentric fold axial planes (s_3) reflect a third large fold variety.

Quartz diorite to granodiorite dikes, correlated with the emplacement of the Idaho batholith, are not folded and therefore were emplaced after the third episode.

Cataclastic microshear folds, present locally, reflect the fourth episode.

DATING OF AN ANTLER OROGENIC PHASE (MIDDLE MISSISSIPPIAN) IN WESTERN UTAH

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An angular unconformity between the Chainman formation and folded older rocks has been mapped in the Silver Island Range northeast of Wendover, Utah. Folding of the pre-Chainman formations occurred in early Valmeyer (Middle Mississippian) time. The folding postdates the Joana limestone of early Valmeyer age (*Spirifer grimesi*) and predates the Chainman formation containing crenistriate *Goniatites* (about middle Valmeyer). This disturbance is designated as the "Wendover phase" of the Antler orogeny. Evidences for the above conclusions are:

(1) The lower clastic facies (A) of the Chainman formation, which contains crenistriate *Goniatites* and *Ekvasophyllum*-type corals, rests unconformably upon post-Joana folded Guilmette limestone, Pilot shale, and Joana limestone.

Other (ascending) Chainman facies are: (B) a carbonate facies which thickens eastward and contains striate *Goniatites* (late Valmeyer and early Chester); (C) a dominantly shale sequence, which coarsens upward and contains *Cravenoceras* and *Eumorphoceras* of later Chester time; and (D) an eastward-thinning clastic facies, correlative in part with the Diamond Peak facies, which contains *Rhipidomella nevadensis* and *Spirifer occidentalis* (early Pennsylvanian).

(2) From Pioche, Nevada, to the Confusion Range clastic facies (A) rests on the Joana limestone and thins progressively northward from 530 feet to 215 feet. In the northern part of the Confusion Range facies (B) overlies the Pilot shale which is chiefly late Devonian (Famennian). Thus, the Chainman oversteps older strata.

(3) South of the Confusion Range facies (A) is mainly siltstone, whereas in the Silver Island Range cherty sandstone and conglomerate are locally abundant.

(4) Effects of the Wendover phase appear to be recognizable in the vicinity of Eureka, Nevada (T. B. Nolan *et al.*, U. S. Geol. Survey Prof. Paper 276, p. 55, 58).

GEOLOGIC HISTORY OF THE SILVER ISLAND RANGE, UTAH AND NEVADA

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During Paleozoic time 23,000 feet of miogeosynclinal sediments was deposited in the Wendover, Utah, area. Physical and faunal evidence in the Silver Island Range indicates the following unconformities: (1) late Cambrian paraconformity—Notch Peak formation overlies Weeks formation; (2) middle Ordovician paraconformity—Eureka quartzite overlies Crystal Peak dolomite and shaly quartzite member; (3) early Silurian paraconformity—Laketown dolomite overlies Fish Haven dolomite; (4) early Devonian paraconformity—Simonson formation overlies Laketown dolomite; (5) very late Devonian angular unconformity—Joana limestone overlies Guilmette limestone and Pilot shale; (6) middle Mississippian angular unconformity—Chainman and Diamond Peak formations undifferentiated overlie northeast-southwest folded Guilmette limestone, Pilot shale, and Joana limestone; and (7) Pennsylvanian angular unconformity or disconformity—Virgilian strata overlie early Morrowan (?) Chainman and Diamond Peak formations undifferentiated to Desmoinesian Ely group.

No Mesozoic or early Tertiary deposits are exposed in the Silver Island Range. North-south folding, subsequent faulting, and intrusions of granitic to dioritic stocks and dikes are dated as post-Permian and pre-early Pliocene.

Late Tertiary geologic episodes were as follows: (1) early Pliocene sediments (Salt Lake group—

3000+ feet) were deposited unconformably on Paleozoic rocks; (2) block faulting occurred in post-early Pliocene time and seemingly prior to the extrusion of volcanic rocks; (3) rhyolite porphyry and andesite porphyry lavas were extruded unconformably on Paleozoic and early Pliocene sediments.

Elevations of Lake Bonneville levels are Bonneville—5204 feet, Provo—4834 feet, and Stansbury—4484 feet, suggesting warping relative to the eastern Bonneville Basin during Pleistocene time.

ENGINEERING GEOLOGY AND URBAN GROWTH—A CASE HISTORY

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Fulminating populations in some urban areas have used up acceptable building sites. Stability problems in new subdivisions in coastal, flood-plain, and hillside environments become increasingly more complex. Los Angeles is an area which has become the proving ground for unique control regulations.

Los Angeles has experienced tragic and costly damage from landslide, mud flow, rock avalanche, runoff, earthwork failure, ground subsidence. Following extreme casualty in 1952, the City enacted the "*Grading Ordinance of 1952*" which is considered a model for control of grading operations. A system of mandatory permits, inspections, and certifications in certain arbitrarily designated hazard areas has proven itself in practice.

The City Council in 1958 appointed a Geological Hazards Committee composed of geologists, foundation engineers, civil engineers, and landscape architects to advise in the field of engineering geology. The Department of Building and Safety, after conference with the Geological Committee, established a *Board of Qualifications for Engineering Geologists* to establish a roster of qualified engineering geologists. "Field schools" were set up to train inspectors in elementary geology, and ground work was laid for the preparation of a city-wide geological hazards map.

Experience in examining applicants indicates that basic *engineering training* for engineering geologists is generally inadequate. Conversely, basic *geological training* for foundation and other civil engineers in allied work is practically nonexistent.

The interest of other government jurisdictions in this first experimental qualifications Board for engineering geology seems to indicate that increasing demand is inevitable for engineering geologists with stronger training in basic engineering.

MIOCENE METEORIC DUST

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Dominantly spherical and spheroidal microscopic particles ranging in size from 50 to 880 microns have been observed in well cuttings and cores of sedimentary rocks of Cretaceous, Miocene, and Pleistocene age from the Sacramento, San Joaquin, and Ventura basins of California. The particles are dominantly magnetic and metallic and range in color from black to silver gray. The metallic spheres are hollow, but many of the black, nonmetallic individuals contain single or multiple metallic cores. The surfaces of the metallic particles are highly detailed by intergrowth phenomena similar to the Widmanstaetten figures observed in nickel-iron meteorites. Most of the chemical analyses for nickel were positive. Pockmarking and solidified gas bubbles were observed on some exteriors.

Similar objects have been reported from all parts of the United States by workers sampling debris from the present atmosphere. These have been described both as fly ash, a byproduct of the industrial use of powdered coal, and as particles of meteoric dust of extraterrestrial origin. The similarity of the spheres, from the well cuttings and cores, to fly ash is noted, but the positive nickel tests, the Widmanstaetten figures, and the certain Miocene age of the spheres in the core material preclude the possibility of these particles being modern fly ash. It is proposed that these spherical particles are the remains of debris of meteorite showers which fell into sites of active sedimentation as long ago as Miocene time.

PETROFABRIC STUDIES OF METAMORPHIC WALL ROCKS OF THE NORTH END OF PIKES PEAK BATHOLITH, COLORADO

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Petrofabric study of biotite cleavages and c axes of quartz in oriented thin sections from Idaho Springs gneiss units near the contact of Pikes Peak granite with Idaho Springs gneiss units shows the effects of regional forces and granitic intrusion upon the orientation patterns.

Fabric patterns of biotite show a very strong tendency for preferred orientation although the pattern of orientation is slightly variable in different samples. Quartz shows much less tendency for any preferred orientation.

Biotite in all the rocks shows one strongly developed *S* surface and a set of two or three subsidiary *S* surfaces which intersect along a line and produce a rotational tectonite pattern. This is accounted for by the effect of regional folding movements.

The rocks have been soaked with large amounts of granitic material which was introduced along the major foliation planes and, in places, moved across these planes isolating the gneissic material within a granitic matrix. Presence of this introduced material aided in the development of a plastic rotational movement in biotite flakes giving rise to a variation in the direction of the *S* surfaces.

The quartz-axes diagrams have a tendency toward a rotation girdle pattern. The axis of the girdle lies subparallel to the rotation axis of the various *S* surfaces and may be called the *b* fabric axis.

Petrofabric diagrams reveal that regional folding movements played a major part in causing the orientation patterns. These have been modified to a certain degree by introduction of granitic material along foliation planes during the final stages of batholithic emplacement.

QUATERNARY HISTORY OF UPPER BAKER VALLEY, WASHINGTON

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The following geology was determined at the Upper Baker Dam project southeast of Mt. Baker. (1) Major erosion cycle—preglacial valleys cut in bedrock to El. 187; (2) first glaciation—thick, compact tills laid on bedrock; (3) erosion cycle—valley cutting in till by ancestral Baker River; (4) aggrading cycle—chiefly sand and silt with some small gravel; (5) eruption of No. 1 andesite; (6) second glaciation—till in most places less than 25 feet thick resting on alluvium at El. 300; (7) deposition of varved clays in lake basins; (8) erosion cycle—partial removal of varved clays following drainage of lake occupying the floor of ancestral Baker River Valley at El. 400±; (9) eruption of No. 2 andesite which partly filled the ancestral Baker River and compacted and disturbed the underlying varved clay. Lava stringers filled small valleys tributary to Baker River. Maximum thickness 350±. Sulphur Creek, Baker River and Sandy Creek displaced. (10) continued erosion—cutting of new channels by Baker River, Sulphur Creek, and Sandy Creek; (11) eruption of No. 3 andesite; (12) ice dam in Skagit River—extensive varved-clay deposits buried by advancing gravel and sand deltas of Sulphur and Sandy creeks, as evidenced by widespread foreset bedding; (13) present valley-cutting cycle developing a main terrace at El. 720 and terraces at lower levels in previous deltaic deposits. No. 2 lava exposed in Sulphur Creek and Baker River with development of Horse Bridge and Sulphur Creek Springs.

CALDERA SUBSIDENCE IN THE CREEDE AREA, SAN JUAN MOUNTAINS, COLORADO

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The Creede caldera, a subcircular collapse feature about 10 miles in diameter, is the major structure in the central San Juan Mountains, Colorado. The margin of the caldera is clearly defined by a

moatlike trench, which is followed by the Rio Grande and tributaries through an arc of more than 300 degrees.

Caldera subsidence probably began catastrophically with the collapse of a rhyolitic volcano following eruption of a great volume of pumice. Volcanic activity continued in the area, and welded tuffs accumulated from several centers. A new and larger caldera, including all but the northern margin of the old caldera, subsided intermittently concurrently with these eruptions. Details of subsidence are recorded in the subcircular core of the caldera by the intertonguing of welded tuffs with debris from the caldera walls. Faults that extend outward from the caldera were active intermittently during and after caldera collapse.

Following subsidence and filling, the central part of the caldera core was arched upward, and the crest of the arch was broken by graben faults. The border of the caldera remained low, forming a structural valley or moat around most of the periphery. Viscous magma rose along faults near the caldera border to form local volcanic domes and flows. Drainage in the structural moat was dammed, and stream and shallow-lake sediments of the Creede formation accumulated over most of the caldera border.

Subsequent erosion has removed much of the Creede formation, exhuming and modifying the structural topography formed by arching and faulting in the core of the caldera.

GEOLOGY OF THE MELROSE AREA, BEAVERHEAD AND SILVER BOW COUNTIES, MONTANA

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The Melrose area, 144 square miles, located 25 miles southwest of Butte, Montana, includes 15,000 feet of intensely deformed miogeosynclinal strata deposited along the eastern edge of the Cordilleran geosyncline. The highly deformed strata range in age from Precambrian through Mesozoic. Tertiary sediments unconformably overlie the older strata. Late Pleistocene alpine glaciation occurred in the highland areas.

Late Cretaceous–Eocene quartz monzonite-granodiorite stocks, dikes, and sills represent the southwest margin of the Boulder batholith. Andesite and basalt extrusives which are present in small areas appear related to fault fissures.

Initial forces (Middle to Late Cretaceous) of the Laramide orogeny caused deformation that preserved the strata in a relatively downwarped north–south zone lying between two marginally uplifted areas, the Highland Mountains and Pioneer Mountains. Continued compression of the strata within the downwarped area produced orogenic-type forces that intensely deformed the strata into parallel, northwest-trending, asymmetrical synclines whose southwestern flanks are overridden in various degree by the easterly overturned thrust- and high-angle faulted east flanks of the adjoining anticlines. Final structural adjustments caused cross-faults, small-scale imbricate thrusting, flow folding, and compensating minor folds. Tilted Oligocene strata suggest epeirogenic uplift of the general area to its present elevation during the Pliocene. Rejuvenated fault scarps and recent earthquakes attest to continued tectonic activity.

Resources include gold-silver-lead veins, phosphate rock, manganese, silica, and small amounts of bentonite. Eighty-one million short tons of mineable furnace-grade sedimentary phosphate rock are present in the Permian Phosphoria formation.

DIFFERENCES IN THE PLIOCENE-PLEISTOCENE HISTORIES OF THE UPPER ARKANSAS AND THE EAGLE RIVER VALLEYS, COLORADO

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The upper Arkansas and Eagle rivers of central Colorado head on opposite sides of the Continental Divide near Tennessee Pass. From its head southward for 70 miles to the vicinity of Salida, the Ar-

kansas Valley is choked with deposits of late Tertiary and Pleistocene age, at places many hundred feet thick. The Eagle Valley contains little fill throughout its 50-mile length.

The fill in the Arkansas Valley includes: (1) Pliocene fluviatile deposits, locally several hundred feet thick; (2) older pre-Wisconsin till, sheetlike in form, deeply weathered, and low on the valley sides; (3) an irregular blanket of gravel related in origin to a widespread pediment, pre-Wisconsin in age, which is beveled over bedrock, Pliocene strata, ancient drift, and gravels alike; (4) high-level remnants of a younger pre-Wisconsin till; (5) large lateral and terminal moraines of early Wisconsin age, which lie in valleys excavated below the pediment level; (6) smaller moraines, interior to those of (5), of late Wisconsin age.

In the Eagle drainage, the first three units are absent and either did not form or were removed rapidly. The fourth unit is present, and the fifth—the early Wisconsin—is represented by large lateral but no terminal moraines.

The Eagle River is working headward at a level 600 feet below the Arkansas, and erosion has been rapid. Pliocene and later sedimentation in the Arkansas Valley probably resulted from changes in base level caused by uplift of the Front Range, which the Arkansas crosses, and possibly by late Tertiary lava damming and faulting near Salida.

LOWER CAMBRIAN AND PRECAMBRIAN ROCKS IN NORTHEASTERN WASHINGTON

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Three distinctive formations—a conglomerate and an overlying volcanic unit of Precambrian age, and a quartzite of Early Cambrian age—constitute a group of rocks that can be recognized for nearly 200 miles, from southern Stevens County, Washington, northeastward through part of the Nelson map area, British Columbia. The Precambrian conglomerate, where present near the center of the area, rests unconformably on older Precambrian rocks. The Lower Cambrian quartzite unconformably overlies the younger Precambrian conglomerate and volcanic unit nearer the center of the area, but unconformably overlies the pre-conglomerate rocks to the north and south. In the vicinity of the International Boundary, the Cambrian and Precambrian rocks are essentially conformable.

The unconformity at the base of the Cambrian represents the removal of the Precambrian volcanic unit and conglomerate and a considerable thickness of the underlying older Precambrian rocks at the north and south ends of the area. The unconformity within the Precambrian at the base of the conglomerate represents the removal of considerably less rock.

Scarcity of shallow-water features so common to the rocks of the Belt series farther east, and the presence of carbonate rocks in the sequence of fine-grained clastic rocks in the southwesternmost exposures make correlation of the Precambrian rocks with the Belt inconclusive in this area. It is possible, however, that these rocks represent a facies of the Belt series.

PETROLOGY AND STRUCTURE OF THE SOUTHERN PART OF THE ABSAROKA MOUNTAINS, WYOMING: A PROGRESS REPORT

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The area described is located in the northern one-third of the Kirwin quadrangle, about 50 miles south-southwest of Cody, Wyoming. Approximately one-third of a hitherto unmapped 600-square-mile area containing mineralization, intrusive and extrusive igneous rocks, and volcanic sediments has been mapped since 1951.

Layered rocks are about 5500 feet thick and range in age from Eocene to Oligocene. The Tepee Trail formation (upper Eocene) consists of interbedded volcanic siltstones, sandstones, and conglomerates which rest with angular discordance on the underlying Lower Eocene Willwood formation. The overlying Wiggins formation (Oligocene) is highly variable in lithology. Near the intrusive rocks, it consists dominantly of andesite flows and flow breccias. Elsewhere it is composed of massive

volcanic conglomerates, tuffaceous siltstones and sandstones, flows, and breccias. Andesite, dacite, granodiorite, and rhyolite occur as stocks and dikes. Three of the stocks are believed to represent former vents.

In the northeast part of the area, both the Tepee Trail and Wiggins formations have been displaced by 500- to 1000-foot vertical normal faults. Folds with dips up to 40° also occur here. In the southwest part of the area, a rhyolite stock has intensely deformed the Wiggins formation to the south and uplifted a large block of Paleozoic strata on the north. Elsewhere, the Wiggins varies from horizontal to moderately folded.

Pyrite-molybdenite-chalcopyrite-bearing quartz veins and galena-sphalerite-tetrahedrite-pyrite veins cut the Wiggins formation adjacent to the granodiorite stocks.

NORMAL FAULTING IN THE FLATHEAD RANGE, MONTANA

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Geologic mapping disclosed two sets of normal faults cutting the Belt series and Paleozoic strata:

(1) Longitudinal northwest-trending faults dipping to the west, which are parallel to the range and the strike of the easterly dipping strata. The three faults in this set are:

(a) The Flathead fault, which is a zone up to half a mile wide of gouge, breccia, and large horses along the western edge of the range

(b) The Roosevelt fault, which is a zone of gouge and breccia more than 100 feet wide along the eastern edge of the range

(c) An intermediate fault marked by a zone of brecciated rock up to 100 feet wide

(2) Transverse northeast-trending faults dipping both north and south. These constitute the younger set and displace the two westernmost longitudinal faults.

Shear surfaces in a test pit in the Flathead fault zone dip 60° W. Traces of the Roosevelt and intermediate faults indicate dips to the west. West dips of the longitudinal faults are also indicated by their strike separations along the transverse faults, for which normal displacements are known.

Assuming that these faults are orogenically related to the Lewis overthrust, their normal character implies that they are later in the orogenic cycle than the overthrusting. Some previous investigators have considered the longitudinal faults to be reverse faults dipping to the east. The above data suggest that detailed mapping of other longitudinal faults in western Montana may show them to be normal rather than reverse.

MARINE GEOLOGY—A NECESSARY COURSE IN THE MODERN CURRICULUM

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Marine Geology, although one of the newer aspects of geology, is also one of the more rapidly developing. The many startling advances, both technical and scientific, since World War II particularly in sampling, sounding, temperature, and time have placed at our disposal tools by means of which we may attack not only the problems of recent environments of sedimentation but ones which may enable us to understand better the similar environments which have occurred in the earth's past history.

Many data have been collected during the IGY, which will require trained personnel for their interpretation. Recognition of this need is suggested by the institutes in marine biology and marine geology which will be sponsored by the National Science Foundation this summer. Certain difficulties are encountered in offering such a course at an inland "land-locked" school, but for the most part they are problems which relate to the laboratory only. A practical outline for such a course at an inland school is presented.

ABSTRACTS OF PAPERS SUBMITTED FOR THE MEETING IN JUNEAU, ALASKA, AUGUST 28, 1959 (TENTH ALASKAN SCIENCE CONFERENCE OF AAAS)

REGIONAL GEOLOGY OF THE COOK INLET AREA, ALASKA

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The geologic history has been interpreted according to current hypotheses on mountain building. Surface studies and a literature survey constitute the basic data used in the interpretation.

The Cook Inlet area is geologically similar to both the western Pacific island-arc system and the orogenic belts of western North America.

Late Paleozoic to early Mesozoic eugeosynclinal sediments were deposited in linear troughs subparallel to the present southern coast of Alaska. In Early Jurassic time this area underwent a period of orogeny. The site of the Alaska Range was uplifted and subjected to volcanism and plutonism. The site of the Chugach Range (includes Kenai and Chugach mountains) was concurrently downbuckled into a tectogene and intruded by plutonic rocks.

Epeirogenic marine Mesozoic sediments and nonmarine Tertiary sediments were deposited in the intermontane basin between the Chugach Range and the Alaska Range. Minor volcanism and plutonism has continued to Recent time in the Alaska Range.

Post-orogenic warping and faulting has occurred in areas extensively intruded by plutonic rocks. This later faulting cuts across former orogenic trends in order to adjust to the new continental edge formed by the Early Jurassic orogeny. This trend is not recognizable in the southwestern Chugach Range because movements are taken up by folding and bedding-plane shear in metamorphic rocks.

STRUCTURAL CONTROL OF QUICKSILVER ORE AT THE RED DEVIL MINE, ALASKA

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The Red Devil mine, Alaska's largest quicksilver producer, is in the central Kuskokwim region, about 250 miles northwest of Anchorage. The ore mineral is cinnabar, associated with abundant stibnite.

Detailed mapping indicates that most ore bodies are localized near intersections between altered dikes of Tertiary age and bedding-plane faults in thin- to medium-bedded graywacke and shale of the Upper Cretaceous Kuskokwim group, an interpretation first recognized by John D. Murphy, former manager and geologist at the mine.

The dikes, which strike northeast and dip southeast are offset in en echelon pattern by right-lateral strike-slip faults that strike northwest and dip southwest. Ore bodies are localized in breccia and shear zones at and between the intersections of the dike segments and faults and locally replace nearby parts of the dikes. Most of the known ore bodies form a series of steeply plunging, subparallel, rodlike lodes, which rake 35°-80°S. in the fault planes.

At least three mineralized dikes are recognized which consist of hydrothermally altered basalt or andesite. The faults are clean-cut slips or gouge and breccia zones. Movement along them was mainly strike-slip, but subordinate dip-slip movements are indicated. Apparent fault displacements range from less than an inch to about 20 feet.

RECENT OBSERVATIONS OF GLACIER BEHAVIOR IN ALASKA

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As part of the International Geophysical Year program, parties from the American Geographical Society have carried out observations of glacier variations in many of the more accessible areas of southern Alaska. Termini have been photographed and mapped from previously occupied positions for determinations of qualitative and quantitative changes. Firn limits have been noted, and dating of moraines, particularly those representing the last significant maximum, have been carried out by geobotanical techniques. Related geological and geomorphological features have also been studied.

BEDROCK GEOLOGY AND PETROLOGY OF THE JUNEAU ICE FIELD AREA, SOUTHEASTERN ALASKA

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Near Juneau, the Coast Range batholith is bordered on the west by a belt of progressively metamorphosed rocks, which is subisoclinally folded and overturned to the southwest. The metamorphic grade increases to the northeast across the strike, and the succession includes pelitic schists, impure marbles, quartzites, amphibolites, and Ca-Mg rich rocks.

The westernmost quartz dioritic gneisses first occur as thin gradational intercalations in the pelitic schists and amphibolites of the medium-grade zone. Relict mafic minerals define a schistosity which is inherited from adjacent layers of parent rock. Replacement textures displayed by late sodic plagioclase, K feldspar, and quartz indicate that these rocks are migmatitic gneisses derived from pelitic schists and amphibolites by the metasomatic introduction of Na, K, and SiO_2 during late and post kinematic time.

Migmatitic gneiss layers gradually increase in volume toward the northeast at the expense of transformed parent rocks. The bulk composition of the gneisses grades from granodiorite in the central belt to quartz monzonite in the east marginal belt.

Folds in the central and east marginal belts tend to be open and upright. The isochemically metamorphosed rocks in all belts have experienced two cycles of folding. The earlier folds had a westerly trend.

A 300-foot thickness of relict pelitic schists and amphibolites forms a screen between the west contact of the east marginal pluton and the easternmost occurrence of the migmatitic gneisses. The east marginal pluton is concentrically zoned; it grades from quartz monzonite at the margins to granite near the center of the mass.

Near the International Boundary, the pluton is in sharp discordant contact with low- and medium-grade crystalline schists and an unconformable overlying sequence of andesitic volcanic rocks containing interbeds of tuffaceous conglomerate and graywacke. Rocks of both sequences are locally hornfelsed above the contact.

POST-WISCONSIN GLACIAL CHANGES IN SOUTHEAST ALASKA

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A reconnaissance study (IGY) of glacial deposits near the larger glaciers of Glacier Bay, Klihini-Chilcat drainage, and above Skagway and Juneau reveals a common recent glacial history. Many dated stumps in place on bedrock and interlayered in outwash record 5000 years during which ice had receded farther than it is today (2000 to 7000 years ago). Into valleys reaching lower Glacier Bay and most of Muir Inlet the glacial outwash gradually filled to more than 50 feet above present sea level. Limited areas contained lakes (varved clays) interbedded with this outwash.

Then followed a millenium (more than 1000 to 300 years ago) of pulsating glacier advance, The Little Ice Age; the gravels and lake beds are covered everywhere by 1–30 feet of blue-gray till. Erosion of underlying horizontal beds, grooving of the till, drumlins, and large crag and tail deposits in the lee of many knobs indicate strong basal motion. Distance of advance was roughly proportional to the size of the feeding area; ice in Glacier Bay expanded to Bartlett Cove. Earlier studies date this about 300 years ago with similar recent datings at Crillon Lake (west) and Mendenhall Glacier (east).

Most of the glaciers have receded markedly for the last century. On low slopes and hills in Glacier Bay where historical recession rates of 50 to 500 feet a year were common, small annual (?) moraine ridges were formed; large areas of stagnant ice in marginal basins are still producing kames, hillside channels, and short eskers. These are the subject of continued intensive studies.

GEOLOGIC FACTORS AFFECTING PROPOSED NUCLEAR TEST NEAR CAPE THOMPSON, NORTHWEST ALASKA

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A nuclear test at the mouth of Ogotoruk Creek near Cape Thompson, northwest Alaska, was proposed by the Atomic Energy Commission to determine the feasibility of a large-scale nuclear excavation which will be open to the sea. The geologic studies at the proposed test site were made by the authors and D. W. Scholl of the U. S. Geological Survey, on behalf of the U. S. Atomic Energy Commission.

The results of the studies indicate that the nuclear devices could be placed so as to leave some bedrock south of the largest part of the excavation to prevent its rapid destruction by wave action. A deep entrance would preclude rapid closure by longshore transported sediment. Submarine topography as mapped by the U. S. Geological Survey shows there is a natural approach channel.

The bedrock consists of tightly folded and faulted mudstone, siltstone, and sandstone of the Tiglukpuk formation of Jurassic age. It is overlain by a thin veneer of unconsolidated material. The devices will be placed in 42-inch drill holes, the deepest of which will be 700 feet deep. The more resistant siliceous limestone, which underlies the Tiglukpuk formation, probably will not be penetrated. The holes may pass through areas of unfrozen ground in which caving may be a problem locally.

PHYSIOGRAPHIC CHANGES ASSOCIATED WITH THE SOUTHEASTERN ALASKA EARTHQUAKES

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The July 1958 earthquake (Pasadena—magnitude 8), felt from Anchorage to Seattle, was the largest since the Yakutat 1899 shock. Five lives were lost. Even though the shock ranks as one of the four largest earthquakes in the United States, there was very little property damage; however, extensive physiographic changes were noted. The entire epicentral area has not been studied because of the inaccessibility of the region, but the near-shore investigations reveal extensive faulting along the Fairweather fault between Cross Sound and Yakutat Bay. The horizontal movement was right-lateral and was about 20 feet according to Tocher, whereas the vertical component was northeast side down and averages about half the horizontal figure.

Turner Point of Khantaak Island subsided, and the hydrographic resurvey in Monti Bay revealed abrupt changes compared with a 1942 survey. Along the coasts in the epicentral area the unconsolidated sediments showed water spouts, sand heaves, etc.

The denudation of growth within Lituya Bay, whose northern shore is approximately 10 miles from the Coast and Geodetic Survey epicenter, shows a combination of landslide and water-wave damage. The maximum height of this damage is 1800 feet. The authors believe that the maximum height of the water-waves was no more than about one-fifth of this elevation.

CONTRACTION THEORY OF ICE-WEDGE POLYGONS

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Ice-wedge polygons play an important role in many natural processes in permafrost, and, in addition, their differential thawing represents the most important single cause of road and airfield failure in many areas. Despite their importance, however, the distribution of ice wedges is not well known, and their origin is incompletely understood. Currently there is probably no serious objection to the general view that ice wedges result from the freezing of water in seasonally recurring thermal contraction cracks. Theoretical methods may be used to test certain implications of this contraction theory and to gain insight into the controlling mechanical and thermal processes.

Any linear first-order differential relationship between thermal stress and strain (elastic, Newtonian, Kelvin, or Maxwell models) seems to lead to contradiction with the loose restrictions imposed on the contraction theory by qualitative field observations. It is possible, however, to find a reasonable nonlinear deformation law consistent with the thermal requirements and leading to polygonal dimensions compatible with those observed. The theory suggests that rate of cooling as well as total amount of cooling is important in generating the tensile stress that ultimately causes fractures.

Such an analysis can also be applied to the related problems of polygonal jointing in cooling basalt and in drying mud.

TYPES OF URANIUM-THORIUM DEPOSITS NEAR BOKAN MOUNTAIN, PRINCE OF WALES ISLAND, ALASKA

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Uranium-thorium deposits near Bokan Mountain on the southern part of Prince of Wales island are almost entirely confined to a peralkaline granite boss, about 3 square miles in areal extent, or to an aureole as much as a mile wide, that surrounds the boss. The aureole consists largely of albitized and altered quartz monzonite, granodiorite, and quartz diorite.

Four types of uranium-thorium deposits were recognized during the geologic investigations: (1) epigenetic deposits in which the uranium-thorium minerals occur in veinlets commonly within dikes or peralkaline granite—this is the prevalent mode of occurrence; (2) a deposit in which the radioactive minerals occupy parts of the interstices in clastic metasedimentary rocks; (3) deposits of syngenetic uranium-thorium minerals in pegmatite or aplite dikes; and (4) a deposit in which radioactive accessory minerals in peralkaline granite constitute a small part of a lobe consisting chiefly of uranium-thorium minerals in veinlets.

Many of the pegmatite and aplite dikes contain both syngenetic and epigenetic radioactive minerals.

MUMMIFIED SEAL CARCASSES IN THE McMURDO SOUND REGION, ANTARCTICA

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Mummified carcasses of the "crabeater" seal (*Lobodon carcinophagus*) lie scattered over the landscape 1 to 30 miles from the sea and up to 3000 feet above sea level in the ice-free areas of the McMurdo Sound region, Antarctica. The writers collected information on 90 carcasses.

The carcasses are hard and dry, and lie on the surface of the ground, mostly in valley bottoms. They range from relatively well preserved bodies to merely old twisted wind-dissected fragments of tissue. One carcass dated by radiocarbon analysis is between 1600 and 2600 years old.

The writers believe that, in the Antarctic, seals that occasionally wander inland find no food in the fresh or alkaline lakes and therefore die. Because the arid and cold climate is ideal for retarding organic decay, the bodies do not rot and weather away, as in other climates, but are preserved an incredible length of time. The remains of almost all seals that have wandered inland during the last 2000 years probably still exist.

ORIGIN OF AAPA-MOORS (STRANG- UND RINGMOORE)

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The development of the aapa-moors (Strang- und Ringmoore) in northern Scandinavia is caused by the thawing of the permanently frozen subsurface of moss and fen.

The lamination of the frozen soil in the subsurface of the moors by ice layers and ice lenses is caused by thawing. This action is the result of the thermal currents from the interior of the earth. Such stratification favors the sliding of the frozen upper parts of the moors. Through cracks and fissures and other ways the water runs off. The frozen moorflakes above the ground move laterally. Thus they form scales and walls which are separated from one another by stripes of water (Schlenken). In the interior parts of the walls permafrost ice lenses covered by sphagnum are still preserved.

The palsmoors of northern Scandinavia are mostly formed by the collapse of the permafrost in moors with horizontal surfaces. They were developed by permafrost in sub-boreal time.

SCUBA DIVING OBSERVATIONS ON THE ALASKAN SHELF AND UNDER ICE IN THE POLAR SEA

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Thirty SCUBA dives were made in the Arctic Ocean and Chukchi Sea to gain first-hand knowledge of typical Arctic sea-floor environments and to learn something of the problems of SCUBA divers doing underwater work in polar regions. Dives to bottom were made at a number of locations between Pt. Barrow and Bering Strait in water depths of 50 m. The sea floor was examined and photographed, bottom-sediment samples and biological samples were collected, underwater visibility for dives was noted, and water currents near the bottom were measured. In addition to the bottom dives, three dives were made around and under ice floes.

Off Barrow, in a water depth of 21 m, ridges and irregularities up to 1 m high were found on the sea floor, and these are ascribed to winter-ice movement. Sea-floor sediments range from silt and clay to gravel and cobbles. Gravel is abundant, mixed with sand, silt, and clay sediments; cobbles and, more rarely, boulders are present also. These coarse materials probably are the result of ice rafting. Because the Arctic Ocean and Chukchi Sea have a heavy ice cover much of the year, hydrodynamic sorting of shelf sediments by oscillating bottom currents due to surface swell is small.

In general, the Alaskan Arctic shelf contains abundant molluscan and crustacean faunas. Fish are relatively rare. Kelp and smaller algae were noted on almost every dive, but the mass of it per unit sea-floor area is small compared with more temperate regions.

COMPARATIVE STUDY OF SHALLOW-WATER SEDIMENTS IN THE VICINITY OF BARROW, ALASKA

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At Point Lay, Wainwright, Barrow, the Plover Islands, and Cape Simpson 136 sediment samples were taken along 15 profiles. Sampling began at the water's edge and continued seaward to depths of 12 to 15 feet. Mechanical analysis shows that the usual profile at Barrow and to the southwest starts at the beach with a median diameter of 5 mm or larger and with good sorting. East of Barrow medians are smaller. Immediately offshore medians become larger, the sorting poorer, and the size distribution usually bimodal. Except where ice-rafted material is present, the normal profile shows rapid improvement seaward in the sorting, and the sediment becomes unimodal and much finer (median 0.2 mm.). As shown graphically by histograms plotted "sidewise" beneath the bottom profile, the shallowest bottom profiles and the finest sediments are found east of Barrow where the effective fetch for storm waves is controlled by the distance offshore to the pack ice. Quartz is predominant in the sand sizes both east and west of Barrow; chert is predominant as the coarser constituent at Barrow and to the southwest, quartzite and sandstone to the east.

ABSTRACTS OF PAPERS SUBMITTED FOR MEETING IN CHICAGO, ILLINOIS, DECEMBER 27–30, 1959 (SECTION E, AAAS)

GREAT LAKES WATERS—CIRCULATION AND PHYSICAL AND CHEMICAL CHARACTERISTICS

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The circulation of water in the Great Lakes involves surface and subsurface currents with a seasonal cycle of vertical circulation superimposed. Current patterns are determined by wind, flow-through of drainage water, rotation of the earth, and local influences. Surface currents may have a primary geostrophic relationship to the density field or a secondary relationship in which boundaries or wind set-up play a part. Surface currents lag behind the causative wind by periods ranging from 2 hours in shallow water to a day in deep basins. Current patterns in deep basins apparently involve energy increments from winds of the preceding 10 to 12 days, the increments decreasing exponentially in effectiveness with increasing time prior to the observation day.

Primary physical characteristics of the lake waters are their "soft-water" nature; their seasonal cycles of turnover, lake levels, and precipitation; and their (short-period) seiches. The lakes exhibit a modified seasonal turnover cycle; wind mixing establishes turnover at the end of the fall cooling period and maintains it throughout the winter until the spring warming period is established. Cycles of lake level occur annually: the levels are low in midwinter and high in midsummer. Superimposed upon this cycle are multiyear cycles in level.

In chemical characteristics Great Lakes waters show relationship to their geological ages, their drainage-area rocks, and to their peripheral human-population density. Only Lake Superior has shown no change in chemical characteristics in the past 50–75 years. Lake Erie, oldest and most heavily populated, has deteriorated pronouncedly in chemical water quality during the past hundred years, with increasingly rapid deterioration in the last 50 years.

GROUND-WATER SUPPLIES IN WISCONSIN AND ILLINOIS ADJACENT TO LAKE MICHIGAN

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Ground-water reservoirs in Wisconsin and Illinois adjacent to Lake Michigan presently supply about 200,000,000 gallons of water a day for municipal, industrial, and farm supplies. These reservoirs include the glacial drift, shallow dolomites mainly of Silurian and Devonian age, and deeper sandstone and dolomite formations of Cambrian and Ordovician age.

Most municipal and industrial ground-water supplies in the region are obtained from deeper, permeable sandstone (Galesville, Mt. Simon, and St. Peter) and intervening, locally creviced dolomite formations. Withdrawal of water from these aquifers, mainly in the large industrial districts, has brought about considerable decline in artesian pressures over wide areas. Recharge to the deep aquifers is through the drift and shallow dolomite in the area to the west beyond the limit of the Maquoketa formation of Ordovician age.

The glacial drift and shallow dolomite are sources of water for most farm and many municipal and industrial supplies. High yields due to favorable formation characteristics and recharge conditions are obtained from the shallow aquifers locally, although the over-all ground-water potential is unknown.

The extent to which ground water will be available for future municipal and industrial supplies, particularly around Chicago and Milwaukee, will affect the trend of water-supply withdrawals from Lake Michigan.

ORIGIN OF BERMUDA CAVES

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Throughout Pleistocene time, the calcareous island group of Bermuda has repeatedly been partially inundated and emergent. The land areas have been continuously attacked and reduced by rain and ground water, but they have been recurrently renewed by deposition of marine limestone and, on surviving lands, of shore-borne and wind-transported carbonate sand, now eolianite. At present, the karst topography and the caves are largely below sea level, and their origin must date from times of continental glaciation.

WATER BALANCE OF THE GREAT LAKES SYSTEM

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Part I. The magnitudes of the components of the water balance of the Great Lakes watershed have been the subject of many investigations in the past. The relative merits of various methods that have been used to determine these magnitudes are examined in the light of modern knowledge of evaporation processes, precipitation gauging, and factors affecting stream flow. Especially contentious are the questions of evaporation from the surfaces of the lakes and the amounts of precipitation falling directly onto the lakes. Many of the difficulties involved in assessing the latter factor may be overcome by climatological analyses of weather radar photographs.

Part II. Evaporation from the lake surfaces can be computed by three methods. These are: a water-budget study; a mass-transfer type of analysis; and an energy-budget determination.

Calculations of the latter two types are presented for Lake Ontario, and the results are compared with previous computations of evaporation by the first two methods. The implications of these evaporation computations in determinations of the magnitudes of the other items in the hydrologic balance are discussed. The requirement in water-budget investigations for more and better hydrometeorological data is emphasized.

UTILIZATION OF WATER IN THE GREAT LAKES BASIN: RECREATION

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Recreation is at present an important use of the Great Lakes Basin. Calculable trends indicate that recreation will become even more important in this area. For example, between 1950 and 1957, Michigan's population increased by slightly more than 50 per cent. Comparable figures are available for the other seven states bordering the Great Lakes. The attraction of Great Lakes waters is at least partially responsible for shifts in composition of outboard-motor sales: in 1954, motors of up to 7 horsepower accounted for 14 per cent of sales, those over 20 horsepower only 12 per cent. By 1958 these figures were nearly reversed, 7 horsepower and under representing 17 per cent and 20 horsepower and over representing about 43 per cent of total sales. Real-estate values of recreational frontage on the Great Lakes have increased from an average of $1.50 per front foot in 1945 to $10.00 per front foot today. Value of existing recreational development along the Great Lakes shore line, including private cottages, resorts, and marinas, is conservatively estimated at 1 billion dollars.

Almost certainly growth in population, leisure time, transport facilities, and disposable income will result in increasing competition for Great Lakes waters and frontage between recreational users and the recognized commercial users of the past. Planning and zoning boards should take prompt cognizance of recreational values which occupy a dominant position among the components of a high standard of living.

VISUAL REPRESENTATION OF REGIONAL MORPHOMETRY

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Established morphometric relationships and measures have permitted the theoretical construction of an idealized drainage basin embodying the average linear, areal, and relief characteristics of a homogeneous geomorphic region. Such basins have been constructed from map data for two contrasting regions in which crystalline and metamorphic rocks maintain a high relief—the Unaka Mountains just east of the Great Smokies in Tennessee and North Carolina, and the Dartmoor region of England. The visual representation of these average basins by means of block diagrams drawn to scale provides a useful tool for regional geomorphic description and comparison, as well as helping to bridge the gulf between the quantitative and qualitative approaches to geomorphology.

INFLUENCE OF SCALE IN GEOMORPHIC MAP ANALYSIS

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Quantitative geomorphology depends upon topographic maps, but few studies have analyzed morphometric differences that result from use of different mapping scales. This investigation emphasizes comparison of U. S. Geological Survey or Corps of Engineers topographic maps of 1:62,500, 1:31,680, and 1:24,000 scales. Mapping scales in the Catskill Mountains are compared with those of central New York. Morphometric comparison is made of southern Indiana drainages and of studies by other investigators.

Only blue lines on maps were measured as stream channels in many morphometric studies prior to 1947. Since then most specialists complete the drainage network by drawing additional streams in V-shaped channels. Stream omission on many maps is about 50 per cent, ranging from 30 per cent in 1:62,500 maps to 70 per cent in 1:24,000 maps. Scale differences change drainage density only about 25 per cent but may cause 300 per cent changes in areas of small drainage basins. Maps of the Catskill Mountains show greater disparities than maps of similar scales and dates in central New York. For some terrains a scale of 1:62,500 is morphometrically adequate, whereas for others, a scale of 1:24,000 fails to depict many channels.

Although the scale influences many morphometric parameters, the apparent increase in land and stream slopes with larger-scale maps (1:24,000) is of special importance. These considerations are vital in hydrologic studies, as they determine the measurement of kinetic energy in drainage basins. Quantitative geomorphologists should develop universal indices as standards of reference for terrains of differing characteristics and mapping scales.

ANALYTICAL MODEL OF STREAM EROSION

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The stream profile is regarded as the solution to a boundary-value problem. Given the independent factors, the stream by adjustment of the semi-independent factors (hydraulic geometry) will tend toward equilibrium. If this is not attainable by modification of the channel, then a final adjustment is made by changes in the slope, so that the profile curve satisfies the implied conditions of equilibrium and the requirements of the boundary controls (base level, rock bars, etc.).

Such a treatment will require a set of equations defining the relations among the variables. To attempt this at a hydrodynamical or hydraulic level will lead to mathematically intractable problems. Only at the geomorphic level, and then with the simplest of postulates, can a manageable model be constructed.

The assumption that the rate of flow of sediment load is proportional to stream gradient leads to an equation similar to the one-dimensional equation of the conduction of heat. By adding further terms (Poisson's equation) we may avoid the difficulty of a linear steady-state solution, and by the use of exponential factors we may approximate the general form of natural stream profiles. By analogy with the analytical theory of heat we can employ Fourier's methods to deal with changing boundary values and arbitrary initial conditions to construct a simplified model of rough correspondence to certain classes of natural streams and their response to changes in base level.

The principle of the theory may be extended to apply to valley-slope profiles.

STOCHASTIC MODELS OF CAVERN DEVELOPMENT

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A population of caves evolves from a population of cave precursors, consisting of joint systems of different complexity, which are subject to the invasion of solvent waters whose source, composition, and availability vary in space and time. Although phenomenological theories have had considerable success in the identification and explanation of the succession of geomorphic processes responsible for cave development, these processes also produce manifestations in a cave population related to processes of a random or stochastic nature.

Stochastic models have been constructed to mathematically reproduce the evolution of a particular population manifestation, namely, the distribution of cave lengths. Intuitively "simple" mechanisms for the rate of cave growth and decay have been used for this purpose. The theories provide a quantitative description of the evolution of cave length distributions and, conversely, some attributes of cave precursors which would lead to present-day length distributions. An estimate of the length distribution of all caves more than 100 feet long in West Virginia is used for these comparisons.

The complexity of the evolutionary process of cave populations and the urge to select evolutionary mechanisms which are subjectively simple as well as mathematically tractable are perhaps contradictory; but stochastic-process concepts are essential for a more quantitative understanding of the cavern cycle, and simple models may serve as a point of departure.

ORIGIN OF CAVES IN FOLDED LIMESTONE

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Investigation of caves in folded limestone of the Appalachian region reveals five distinct features bearing on the origin of solution caves: (1) cavern passages develop across the dip or parallel to the strike of the limestone and generally have uniform gentle slope independent of the rock structure; (2) many caves have passages on multiple levels, and, within a region, the separation of levels is uniform; (3) intervals between passage levels correspond closely to intervals between gravel benches on the flanks of major surface valleys in the cavern region; (4) major caves are along large valleys, and only small caves and solution pockets occur in upland areas away from major valleys; and (5) cavern passages decrease in size and become more numerous in the part of the cave away from major surface valleys.

The stages of cavern development in folded limestone beds probably are: (1) random phreatic solution at depth to produce nonintegrated solution tubes and pockets; (2) integration of tubes into mature caverns at the top of the phreatic zone during a period when the water table was uniform in altitude, and flow was constant for a long period of time (direction of flow was toward major drainage ways); (3) deposition of clastic fill under alternating vadose and phreatic conditions; and (4) relative uplift of the cave above the phreatic zone with modification of passages by deposition of speleothems, erosion of fill material, and collapse.

ORIGIN AND GEOLOGIC RELATIONS OF BREATHING CAVE, VIRGINIA

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Thirty or more caves occur in the folded Tonoloway, Keyser, and Helderberg limestones in the southwestward extension of a synclinal segment of the Bullpasture River Valley in west-central Virginia. The limestones, dipping less than 30°, plunge northeast beneath Devonian shale and are again exposed in Bullpasture Gorge water gap.

Breathing Cave, on the northwest side of the valley, in which 3.8 miles of passages has been surveyed, is a rectangular maze of strongly joint-controlled passages in a limited stratigraphic zone. The cave is confined to an 80-foot section of shaly limestone between two sandstone beds and is little affected by numerous minor folds and faults. It follows the dipping flanks of a syncline through a vertical range of 300 feet and displays no development of horizontal integrated levels of passages. A few features considered typical of solution in the phreatic and vadose zones are present, and the cave has been almost filled with sandstone cobble gravel which was later partly removed by vadose streams to produce terracelike levels.

Topography is rugged, with a mature karst developed on the limestone. Subterranean drainage crosses the structural grain and resurges at four springs in Bullpasture Gorge. When surface streams are dry, and accessible vadose cave streams carry 150 gal/min, the springs discharge 8000–9000 gal/min.

The major caves appear to have developed deep in the phreatic zone, in an artesian situation, confined by sandstone interbeds. Vadose streams have alluviated and modified the caves, but most of the ground-water flow and cave development of the present is below the water table.

CLASSIFICATION AND QUANTITATIVE DESCRIPTION OF LARGE GEOGRAPHIC AREAS TO DEFINE ARMY TRANSPORT SYSTEM REQUIREMENTS

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The Army may be required to operate in regions with widely differing terrains and climates. Because of the tremendous diversity of geographic features, simple description of regional geography renders specification of the requirements for military transport vehicles that must operate in all these areas exceedingly difficult. It is therefore necessary to find some unifying geographic characteristics which will permit classification of large geographic areas into a few general categories, within which a data structure may be built in an orderly manner.

An analysis of military geography, with this purpose, has been performed at the Cornell Aeronautical Laboratory, Inc. Large geographic areas were combined into "generic" regions which could be described in detail and which are few enough in number so that the variability among transport vehicles and systems required to operate in different environments could be defined simply. Operational requirements common to all environments, and those unique to particular environments, could then be identified. Within this framework local variability of geographic features and their effects could be identified. The general descriptions may be applied to specific countries, if desired, with appropriate indication of local variations.

This paper describes the method of classification, shows how the quantitative descriptions of the "generic" areas and local geographic features were obtained, and indicates how the data were applied to specification of transport vehicle and system requirements.

MICRORELIEF–PHYSIOGRAPHY–LAND-USE RELATIONSHIPS

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Research was initiated at the U.S. Army Engineer Research and Development Laboratories to obtain data on the variation of microrelief as a function of microwave land-mine detector transmission and reflection. For this paper, microrelief is defined as less than 2 feet and macrorelief as ranging from 2 to 10 feet. Field data were obtained from all the major physiographic divisions of the United States except the Pacific Mountain System. Microrelief data were obtained with a mechanical instrument that measured elevation at 1-inch intervals along a 7-foot traverse and also with a Zeiss P-10 aerial camera to obtain stereo pairs. Data were obtained from average and "typical extreme" conditions in various land-use areas of each physiographic province that were considered applicable to the basic problem of microwave phenomena in soil. A quantitative classification system of microrelief has been devised which is based upon the factors of height, width, frequency, datum-plane width, elongation, and element geometry. Field data in the Coastal Plain, Piedmont, Blue Ridge, and Appalachian Plateau provinces indicate a relationship between macroslope, land use, and soil texture. Data presentation is in the form of stereo pairs and cross-section profiles of type sample sites.

SPECTRAL-REFLECTANCE DATA AND THEIR APPLICABILITY TO TERRAIN STUDIES BY AERIAL PHOTOGRAPHY

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This paper reports on spectral-reflectance data obtained with the new portable reflectance spectrophotometer, as they pertain to research in aerial photography. The U. S. Army Engineer Research and Development Laboratories have supported a program involving the examination of 20 different vegetative-mineral surface environs ranging from a hot desert sand plain to an alpine tundra. The spectrophotometer, the only portable field instrument of its kind, scans the spectrum from 250 μ in the ultraviolet to 1500 μ in the infrared. Maximum resolution attained under field conditions is about 7 μ at 500 μ and 15 μ at 900 μ. The sample area scanned is approximately 6 inches in diameter and can be examined in an undisturbed state. Results from undisturbed and disturbed sample areas are commonly markedly different. The authors, therefore, question whether some of the data collected by laboratory spectrophotometers which use disturbed samples truly represent the reflectance properties of aerial photographic subjects. The reflectance data obtained with this instrument provide the information which is needed to select the optimum film-filter combinations. The reflectance data will be accompanied by aerial photography, ground photography and available soil analysis of the sample sites. Several potential applications of spectral-reflectance data to engineering, mineral and water surveys will also be discussed.

RADAR AS A TERRAIN-ANALYZING DEVICE

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Conventional radars can gather terrain information often denied other sensors while automatically performing a concurrent analysis of the data collected. Additional values are the nearly all-weather capability of radar, the relatively large-area coverage possible, and the trend toward geodetic accuracy of PPI-type displays.

K_u-band terrain reradiation curves demonstrate how in World War II the subject use of radar could have precluded an unnecessary loss of lives. The casualties resulted from the inability of

aerial photography to penetrate dense vegetation. Some X- through K_a-band reradiation data show radar's ability to interpret surface textures, moisture content, and snow cover for trafficability purposes and texture and composition for civil engineering and geologic purposes.

In all these applications, radar is stressed not as a panacea for terrain analyses but as a heretofore somewhat neglected valuable adjunct to other means of information collection.

DOMESTIC AND INDUSTRIAL USE AND CONSUMPTION OF GREAT LAKES WATER

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This paper discusses the various uses which are made of Great Lakes water as a water supply. Data will be presented for all states in the United States bordering on the Great Lakes and for the province of Ontario, Canada, which extends almost the entire length of the Great Lakes. Navigation and power, as they affect the use of Great Lakes water, will be discussed by other authors in the Great Lakes Symposium.

Total usage of Great Lakes water will be indicated for the major municipalities by means of treatment-plant capacities and average annual pumpage. Types of industries will be discussed in relation to their process water needs. Included in these types of industries will be, for example: food and kindred products; tobacco manufacturers; textile mill products; apparel and related products; lumber and related products; chemicals and allied products; petroleum and coal products; rubber products; leather; stone, clay, and glass products; primary metal industries; fabricated metal products; machinery; transportation equipment, etc. This brief list of industries indicates that the major water users for industrial processes will be considered in relation to their consumption of Great Lakes water.

A breakdown will be made with respect to the nature of the use of Great Lakes water within the several states and also with respect to other geographical divisions. An attempt will be made to give complete information regarding present-day uses, and predictions made to at least the year 1975.

AVERAGE SLOPE AND AGRICULTURAL PRODUCTIVITY IN OHIO

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Geographers have not generally approved the average-slope concept. One reason for this is that little significant geographic application has been found. This study re-examines the concept and gives reasons to show that it may prove to be of value in some regions in determining and assigning proper weight to the factors behind the areal variation of agricultural productivity.

To demonstrate this application of the concept, average slope and agricultural productivity in Ohio were compared. An adaptation of the Wentworth method was used to determine the average slope for each county of the state. County agricultural-productivity indexes were derived chiefly from 1950 census data. The average-slope values and the productivity indexes were then compared by means of scatter diagrams.

The relationship is striking: roughness of terrain, as quantified by average-slope measurement, is very important in the areal variation of agricultural productivity in Ohio. The causes of this relationship are discussed. In certain counties, productivity is notably higher or lower than what seems expectable (in Ohio) considering the degree of roughness. These cases reveal the unusually strong influence of factors other than roughness of terrain. Causes of these anomalies are suggested.

The writer believes that the exceptionally strong influence of the other factors would in some instances have remained unrecognized, had not the average-slope concept been applied to the problem.

CHANGING CONCEPTS OF SPELEOGENESIS

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Theories on the nature of the origin and development of limestone caverns underwent systematization in the United States in 1930 as a result of the publication of an important deductive study by William Morris Davis. For some years thereafter, controversy existed as to whether caves are a result of a "one-cycle" process occurring wholly in the vadose zone or a "two-cycle" process having its first phase in the phreatic zone. Field work by many investigators in recent years has indicated some features of caverns which clearly were formed in the phreatic zone and others which were formed in the vadose zone, but this has by no means resolved the controversy.

Comparison of the features of individual limestone caves with those of nearby caves that are at a different stage in a genetic sequence and comparison with caves in different regions suggest that the terms "one-cycle" and "two-cycle" should be abandoned. Emphasis instead should be placed on the specific nature of features of individual caves derived from processes occurring in each of the phreatic and vadose zones. Only in the broadest terms can it be said that all limestone caves develop in the same way, and terminology which suggests that this is true should be replaced by descriptions of individual speleogenetic sequences.

CHEMICAL DEGRADATION ON OPPOSITE FLANKS OF THE WIND RIVER RANGE, WYOMING

Charles H. Hembree and Frank H. Rainwater
U. S. Geological Survey, Washington, D. C.

Rates of chemical degradation of several drainage basins on the northeast and southwest flanks of the Wind River Range in Wyoming have been computed for the 1915–1957 water years. The mean concentrations of dissolved solids for streams that drain the southwest flank, when weighted with water discharge, ranged from 25 parts per million for Pine Creek above Fremont Lake to 34 parts per million for Big Sandy Creek near Big Sandy. The average for all streams on the southwest for which concentrations were computed was about 30 parts per million. The runoff from these basins ranged from 1.87 to 5.43 acre-feet per square mile per day, and the yield of dissolved solids ranged from 0.082 to 0.185 ton per square mile per day.

Weighted mean concentrations in the stream on the northeast ranged from about 40 to 80 parts per million and averaged about 50 parts per million. Bull Lake Creek had a weighted mean concentration of about 50 parts per million. The runoff for Bull Lake Creek basin was about 2.00 acre-feet per square mile per day.

The dissolved-solids yield for most of the streams on the northeast is greater than for those on the southwest; the southwest flank has the greater rate of stream runoff. The greater rate of chemical degradation on the northeast may be due mostly to the effect of a girdling bank of pre-Tertiary sedimentary rocks that is not exposed on the southwest flank.

GEOLOGIC FRAMEWORK OF THE GREAT LAKES BASINS

Jack L. Hough
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The Great Lakes basins are located in zones of weaker sedimentary rocks which apparently were excavated as major valleys by normal processes of stream erosion and then were deepened and reshaped by glacial ice during the Pleistocene. The lakes, insofar as is known, began late in the Pleistocene when the margin of the wasting continental ice sheet retreated northward into the lake basins. The early ice-margin lakes expanded as the glacial ice masses shrank, and they were constricted by temporary readvances of the ice front. At some times of ice-front retreat, the lake waters found new, lower outlets to the north, and the lakes periodically drained down to lower levels—only

to be returned to higher levels when the northern outlets were closed by ice readvance, or, finally, by uplift of land to the north. Downcutting of the southern outlets by the outflowing streams has resulted in a lowering of some of the lakes. In summary of the history, the forms and levels of the lakes have undergone large variations. Continued uplift of land to the north and continued erosion of shores and of outlet channel floors are the cause of slow but still continuing changes in the lakes.

The older rocks of the region are sources of materials for the steel, concrete, and other industries, and they supply the bulk of the materials carried by lake vessels. Pleistocene deposits provide gravel, sand, clay, and other materials of commercial value. Old, raised beaches are used as railway and highway routes. Abandoned former outlet channels have been developed as canal routes.

REGIMEN OF THE GREAT LAKES AND FLUCTUATIONS OF LAKE LEVELS

William T. Laidly
U. S. Lake Survey, U. S. Corps of Engineers, Detroit, Mich.

The average elevation of Lake Superior, the highest in the Great Lakes chain, is 602 feet above sea level. From Lake Superior the water levels drop via the St. Marys River to elevation 580 feet on lakes Michigan and Huron, via the St. Clair and Detroit rivers to 572 feet on Lake Erie, via the Niagara River and Welland Canal to 246 feet on Lake Ontario, and thence through the St. Lawrence River to sea level in the Gulf of St. Lawrence. The lakes range in average depth from 58 feet in Lake Erie to 487 feet in Lake Superior; the shallow portions of their connecting channels are being dredged to provide a minimum depth of 27 feet.

Lake-level fluctuations are classified as seasonal, long period, and short period. Seasonal fluctuations are caused principally by changes in precipitation, evaporation, ground water, and runoff. Long-period fluctuations are caused primarily by long-range changes in the factors affecting seasonal variations, especially precipitation, and to a small extent by vertical movement of the earth's crust. Short-period fluctuations result from wind, differences in barometric pressure, and seiches caused by these two factors. In addition artificial factors such as dredging and construction in the outflow rivers and diversions of water into, out of and within the basin have caused variations. The present net effect of all artificial factors is a lowering of about 4 inches on lakes Michigan and Huron and 3 inches on Lake Erie and is practically zero on Lake Ontario. These artificial factors do not affect Lake Superior because the lake levels are regulated by a control structure in the St. Marys River.

GEOMETRICAL BASIS FOR CAVE INTERPRETATION

Arthur L. Lange
Cave Research Associates, Berkeley, Calif.

The shapes of cave structures can be a key to understanding the evolution of the cave, since they are the result of erosive and depositional processes acting on the cave boundaries. Any future outline of a uniformly dissolving or encrusting cross section of wall, ceiling, or floor is generated by a circle rolled with its axis everywhere in contact with the initial outline. The envelope described by the circle represents the new contour, and the radius is dependent on the mass transfer rate and the duration of the action. In the case of the three-dimensional body, a generating sphere will yield the correct form. This procedure is a geometrical interpretation of the differential equations expressing the event.

Sharp projecting corners will remain sharp while dissolving and will round off when encrusted. Inside corners will round off under solution and remain sharp during deposition. The resultant topographies of complex wall patterns are typical of the scalloped solution-work and bulbous encrustation found in caves where corrasion, gravity, and other directional agents have not modified the basic mechanism.

Plane walls, inundated stalactites, and right-angled ceiling blocks serve as examples of simple geometrical structures. Solution pockets, mammillary crusts, domes, gours, crusted strands, and wall niches are examples of more complicated forms. A cave stream flowing normal to a cross section and an evenly circulating water body or film are cave media in which the process of uniform mass transfer can be closely approximated.

MEASURES OF CORRIE (CIRQUE) DEVELOPMENT IN SCOTLAND

David L. Linton
University of Birmingham, Birmingham, United Kingdom

Field examination during the period 1930–1955 permitted the recognition and location of about 452 Scottish corries on the 92 sheets of the 1:63,360 Ordnance Survey maps. Of this number 401 lie in the west of the country (eastings 150 to 255 km on the National grid—roughly 6°W. to 4°W.) and 51 are central (eastings 255 to 340 km—4°W. to 3°W.); none occur in the east (eastings 340 to 410—3°W. to 2°W.). Graphic plotting of all corries by floor altitudes and easting reveals that, although in any meridian corries may range in altitude through 1000 feet or more, the whole cohort (group) of corries rises eastward. Median values of 1000 feet at easting 150 km (6°W.) and 2650 feet at 300 km (3°30′W.) indicate a general rise of 1100 feet per 100 km.

These relationships strongly suggest climatic causes. Comparison of the distribution of Pleistocene corries with those of present-day precipitation (Great Britain, annual average rainfall 1881–1915, 1:625,000, Ordnance Survey, 1949) reveals important correspondencies. Three hundred and thirteen corries lie inside the 90-inch isohyet; west of the main climatic divide and north of grid line 850 north (57°30′N.), none lie outside it. East of the divide and north of grid line 850 north, 99 corries lie between the 90-inch and 70-inch isohyets, and the 38 northeasterly corries of Scotland lie beyond even the 70-inch isohyet. Diminishing precipitation eastward was evidently compensated by increasing average altitude, diminishing temperatures, and greater snow conservation. If modern values of precipitation and lapse rate are any guide a 30-inch drop in precipitation was offset by a drop in temperature of 5° or 6° F.

USE OF RECHARGE CHARACTERISTICS FOR QUANTITATIVE ANALYSIS IN GEOMORPHOLOGY

Ward S. Motts
Roswell, N. M.

The quantity of water per unit area that percolates to the water table may be used as a significant factor in quantitative geomorphic analysis. The field of hydrology has greatly advanced with development of sophisticated techniques to measure stream recharge. Little thought, however, has been given to interstream recharge, despite its importance in major geomorphic processes such as landscape development and stream development. Accurate interstream recharge studies may be accomplished in a local area, an alluvial fan or flood plain, by means of lysimeters. From the data collected, curves can be constructed showing such relationships as frequency and amount of rainfall to amount of percolation; amount of percolation to slope; or amount of percolation to soil type. Regional recharge correlations could be made from similar studies in different areas.

Interstream recharge studies may be made with worthwhile results by use of semiquantitative methods. Representative soil samples were collected from sinks in the Roswell basin, New Mexico, on an auger drilling program and were analyzed for size, sorting, and permeability. From these data the sinks were mapped in terms of permeability coefficients as well as soil type. From detailed soils maps, an estimate of the permeability and recharge characteristics of soils on river terraces is obtained. The permeability of major soil types is determined by lysimeter tests or by laboratory determinations. Thus, quantitative values of recharge are assigned for the soil types from which the amount of interstream recharge may be estimated.

DEVELOPMENT OF THE TRANSPORTATION NETWORK IN THE GREAT LAKES BASIN

Carl W. Muhlenbruch and Robert C. Stuart
Educational and Technical Consultants, Inc., Evanston, Ill.

The present metropolitan centers and larger cities on the Great Lakes grew out of the waterways transportation pattern of the French and Indian Wars. Early trading posts became the commercial centers and today's metropolises. Major ports for the exportation of natural resources, mainly minerals and forest products, generally did not develop as commercial centers. Early needs for water transportation necessitated the use of these ports for inbound commodity shipments as well as machinery and coal. The transition from major shipments by water to those by rail in the early 19th century led to major rail centers in the same metropolitan areas. Commercial centers developed at rail and highway centers, while other port cities in many cases reached the zeniths of their development. The orientation of the Great Lakes has established travel patterns that exist to this day. Lake Michigan in particular has contributed to the importance of Chicago as an interchange point for all forms of transportation. Even the advent of the airplane has not substantially changed intercity passenger travel, the movement of mail, or the movement of freight across Lake Michigan.

The writers suggest that the development of transportation systems that can best exploit the resources of the area must be planned in a comprehensive manner. Combination highway-rail-ship connections for freight are suggested as a means of supplementing the present car-ferry system. The development of a high-speed route across Lake Michigan for passenger travel does not appear to be economically feasible. The mistakes of the past offer some specific suggestions for future planning.

AREA SAMPLING FOR TERRAIN ANALYSIS

Louis Peltier
Midwest Research Inst., Kansas City, Mo.

Sampling can speed up analytical investigations of large areas or comparison between widely separated areas. Point, transect, and area sampling are compared. Random and regular patterns of sample selection are discussed. Data may also be collected by use of gaming techniques.

For areas involving considerable difference in latitude a latitude correction is desirable if geographical co-ordinates are used as a basis of sample selection.

For studies involving larger or widely separated areas, it is generally necessary to resort to simple interpolation of data—*e.g.* use of known correlations between available information and the desired measurement to indicate factors such as relief and rainfall. By such means estimates of the frequency distribution may be obtained for such elements as slope, local relief, height of valley walls, width of valleys, spacing of drainage ways, and visibility.

Examples of small area and global sampling are presented.

RECESSION OF GREAT LAKES SHORE LINES

Howard J. Pincus
Dept. of Geology, The Ohio State University, Columbus, Ohio

The factors contributing directly or indirectly to the recession of shore lines are readily identifiable in general terms, but evaluation of their relative importance and their interaction in a given situation requires more than generalized analyses.

For example, study of the effects of each of the several types of fluctuations of lake levels on mass movements of unconsolidated bluff materials requires attention not only to the level of wave attack, but also to related fluctuations of the water table, the vertical sequence of bluff materials, the influence of vegetation and of the works of man, and so forth. Further, some stretches of Great Lakes shore lines owe their shapes to their exposure to narrow sectors of incident energy, the small sector angles arising from the combination of fetch geometry and the screening of protective structures.

Modifications of classifications developed earlier this year for the shore-line features of and incident energy along the Ohio section of Lake Erie aid discussion on an areal basis of recession factors. Statements sometimes made about the inferred effects of single factors, such as variations in lake levels, are shown to be oversimplifications.

MORE FRUITFUL USE OF GREAT LAKES WATER THROUGH LEGISLATION, INVESTIGATION, AND CO-OPERATION

H. W. Poston
U. S. Public Health Service, Chicago 7, Ill.

The population of the United States is increasing at an astonishing rate, and it is believed that in only 15 years three-quarters of its people will live in 185 metropolitan areas.

Science is providing a higher standard of living through new processes which will make domestic life easier and industrial production more abundant. Increased mechanization has placed such a demand on our water resources that domestic use has increased fourfold and industrial use eightfold since 1900. By 1980, according to present estimates, the demand for public and private water supplies will double again, and the industrial demands for water will triple.

As the need for water becomes more acute and metropolitan areas extend their search for fresh water, attention will be directed to one of the world's most important sources—the Great Lakes. Each day the significance of the lakes becomes more noticeable, as national and international problems arise concerning their use for water supply, waste disposal, power, and transportation.

The natural supply of water to the Great Lakes is virtually constant, and a great majority of this is lost through evaporation and transpiration. In essence, the water problem is to make maximum use of that which is left. This can be done only with the continued understanding and co-operation between metropolitan areas of the Great Lakes area, both in the United States and Canada. Through this understanding and co-operation, investigations can be made which will serve as the foundation for legislation regulating the use of Great Lakes water with maximum benefit to all.

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The topography of the Great Lakes drainage basin shows effects of former continental glaciation. Minor land forms include moraines, till plains, drumlins, outwash plains, and scoured bedrock ledges. Adjoining the Great Lakes are discontinuous lacustrine plains formerly inundated at higher lake stages. At certain parts of the shore, wave erosion has left steep bluffs. Elsewhere the shores include stretches of high and low dunes, low plain defended by bedrock reefs, and bedrock cliff. The glaciated terrain of the drainage basin contains many undrained basins holding swamps or small lakes.

The drainage pattern shows some relation to bedrock structure and patterns of moraines, although much of it is aimless. The Great Lakes basins dominate the gross drainage pattern, and their trends and forms reflect the underlying rock structure and resistance. Tributary streams within the glaciated areas may reflect the trends of moraines—*e.g.* the DesPlaines River of Illinois and the Milwaukee River. Some smaller streams on lacustrine plains reflect trends of beach ridges parallel to the shore—*e.g.* the Calumet River of Indiana.

WEATHERING AND GEOMORPHIC DEVELOPMENT

B. N. Rolfe
Sinclair Research Laboratories, Inc., Tulsa, Okla.

The geomorphic development of landscapes may be reconstructed by means of weathering and sedimentation studies. Weathering profiles of rock sections in areas of positive relief provide data for defining the climatic regime that was effective during rock weathering. Sedimentological studies of recent detritus from such weathering sites provide information on the kind of erosion pattern responsible for moving the detritus.

An upland site has a vertical profile of weathering that reflects the climatic regime responsible for its development. Such a profile is characterized by chemical, textural, and mineralogical sorting into horizons. The soil material from these weathering sites can either be stripped sheetwise or be carried out during gully dissection. The detritus resulting from each of these processes is distinctive as to texture, chemistry, and mineralogy, so the erosional process can be reconstructed from the study of the resulting sediments.

Weathering and erosional processes contribute to geomorphic development. Present and ancient land forms may be better reconstructed through study of weathering and sediment data.

INSTRUMENTATION SYSTEM FOR MEASUREMENT OF STRESS-STRAIN RELATIONSHIPS OF SOIL

I. J. Sattinger
The University of Michigan, Willow Run Laboratories, Ann Arbor, Mich.

The continued development of land locomotion into a rational science requires that an organized body of information be made available to the designer and user of cross-country vehicles concerning the physical characteristics of the terrain over which these vehicles must travel. An instrumentation system is currently being developed by the Willow Run Laboratories for the Land Locomotion Laboratory of the Ordnance Tank-Automotive Command, which will provide for the rapid and accurate collection of large quantities of data concerning the strength of various types of soil over which military vehicles must operate.

The instrumentation system, which is to be carried aboard a tracked vehicle, contains two types of measurement devices, a shearmeter and a penetrometer. The shearmeter uses a ring-shaped load plate fitted with cleats. This plate is applied to the ground with a constant vertical loading and provides a measure of the strength of the ground against horizontal thrusts by producing a record of torque *vs.* angle as the plate is rotated. A series of runs made with the shearmeter at three different values of vertical load provides enough data to establish the characteristics of the soil at one point in terms of four parameters of an equation representing horizontal soil strength. The penetrometer measures the strength of the ground against vertical loads by causing a round, flat plate to sink vertically into the ground at a constant rate of speed, vertical force being measured as a function of vertical displacement. A series of runs made with two penetrometers having two load plate diameters provides the data necessary to establish three parameters in an equation representing vertical soil strength. Data collected from the instruments, as well as certain auxiliary data relating to test conditions, are recorded by means of a data-logging system carried aboard the test vehicle, which stores the primary data on magnetic tape in digital form. In the laboratory, the data will be inserted into a digital computer for data reduction and analysis.

TECHNIQUE OF MORPHOLOGICAL MAPPING

R. A. G. Savigear
Dept. of Geography, The University of Sheffield, Sheffield, United Kingdom

During the last decade a new technique of recording the characteristics of surface form has been developed. It grew from the necessity to define micromorphological characteristics during an investigation into the nature of slope form and slope evolution. Its basis is the identification, and recording on a base map, of the breaks and/or changes of slope which delimit morphological units (namely facets, which in section are rectilinear, and elements, which are smoothly curved). The method is relatively objective, since its use depends on the ability of the surveyor to identify and record breaks or changes of slope and not, as in the case of geomorphological mapping, on the identification of land form (*e.g.*, cuestas, river terraces) or of the nature of superficial deposits (*e.g.*, glacial outwash gravels, congeliturbate). The limitations of the technique are imposed by the plotting error of the base map. Depending on the object of the survey the most satisfactory scales have been found to be either at about 1:10,000 or 1:2500 (the British Ordnance Survey "Six Inch" or "Twenty-Five Inch" scales). The method has been used in mountainous and plain country in the United Kingdom and has been successfully tested in the West African arid and humid tropics. An area of about 100 square miles of the southern Pennines west of Sheffield in the United Kingdom has already been mapped.

VALUE OF LAND-FORM ANALYSIS IN STUDIES OF SEMIARID EROSION

S. A. Schumm and R. F. Hadley
U. S. Geological Survey, Denver, Colo.

The analysis of quantitative topographic data by Geological Survey personnel engaged in erosion studies in semiarid areas of Western United States yielded the following relationships: (1) mean annual sediment yield from small drainage basins is related to a ratio of basin relief to length; (2) mean annual sediment yield per unit area decreases with increase in drainage area; (3) mean annual runoff from small drainage basins is related to drainage density; (4) the form of some convex hill slopes is shown by successive profile measurements to be related to surficial creep; (5) asymmetric drainage-basin development, including differences in hill-slope erosion and drainage density, is related to microclimatic variations on slopes of diverse exposure; (6) the cutting of discontinuous gullies is intimately related to a steepening of the semiarid valley floor by deposition; (7) aggradation in ephemeral streams appears to be most prevalent in reaches where the downstream increment of drainage area to channel length is relatively small; (8) stream-channel shape, expressed as a width-depth ratio, is related to the percentage of silt-clay in channel and bank alluvium; (9) downstream variations in stream-channel dimensions, independent of variations in discharge, can be related commonly to changes in the silt-clay content of channel and bank alluvium.

These relationships, most of which cannot be detected without actual measurement of terrain characteristics, suggest the effect of terrain on hydrologic variables and conversely some effects of erosion process and sediment type on terrain components.

PRELIMINARY INVESTIGATIONS OF A METHOD TO PREDICT LINE-OF-SIGHT CAPABILITIES

Joan B. Snell
Quartermaster Research and Engineering Center, Natick, Mass.

Recent developments in line-of-sight communications and surveillance equipment make it desirable to analyze the geometric properties of the earth's surface which affect the operation of such equipment. A preliminary investigation has shown that predictive techniques can be used to determine the extent to which terrain features hinder lines of sight. For this analysis, consideration has been limited to equipment which has line-of-sight capabilities for 20 miles over smooth earth and to the ability to see into valleys from a specified point.

A mathematical model of terrain has been devised from which it is possible to predict the number of valleys which cannot be seen (protected valleys) at specified distances from the highest elevation within an area. Given dimensions of relief, average slope, and valley spacing for a particular area, one can construct the model by computing dimensions for other terrain factors which will affect line-of-sight. Figures for valley depth, distance between ridges and valleys, the angle a line-of-sight makes between the highest point and the lowest point, and the distance from valley to ridge along a line-of-sight result in an angle of valley entrance which is converted to a percentage of protected valleys.

This model has been tested in two areas of widely contrasted terrain, in Vermont and Arizona. Comparison of the predicted number of protected valleys with the actual number for both areas reveals that the trend of prediction follows the trend of what actually occurs.

TERRAIN MASK ANGLES

Arthur Stein
Cornell Aeronautical Laboratory, Inc., Buffalo 21, N. Y.

Terrain mask-angle distributions are highly important in establishing the requirements and capabilities of several types of military equipment, particularly those which depend on line-of-sight. To demonstrate the feasibility of obtaining such distributions to required accuracy on a wide scale by sampling techniques, such distributions were generated for terrain in a 30 by 60 mile area in Pennsylvania.

OBJECTIVE FIELD SAMPLING OF TERRAIN PROPERTIES

Arthur N. Strahler and Donaldson Koons
Columbia University, New York, N. Y.; Colby College, Waterville, Me.

Objective, quantitative terrain analysis useful in military and engineering applications measures purely physical properties of the ground surface relevant to the given problem. To evaluate ease of dispersed cross-country movement on foot or in vehicles, an element of ground surface may be analyzed in terms of resistive forces set up by ground slope, surface roughness, soil weakness, and vegetation. Inhibition of movement depends upon the sum of these resistive forces weighted on a performance basis.

A summer field sampling program in central Maine provided data on mean values and variances for within-area and between-area analysis of three basically different terrain types with a wide range in geological properties: (1) bouldery thin till on granitic bedrock with hardwood forest, (2) bog on clay with hemlock forest, and (3) sand plain with pine forest. Roughness, or microrelief, was sampled on random 100-foot transit lines with a logarithmically scaled level rod, measuring all height differences greater than 0.1 foot. Resistance of surficial soil to shearing was sampled uniformly along these sight lines by a Corps of Engineers cone penetrometer. Determinations of remolding index, bulk density, field moisture content, organic content, and grain-size distribution provided additional soil data. Trunk diameters and tree frequency were measured in 40-foot sample circles located by random azimuths and distances. Significant differences exist in means or variances between areas, suggesting the practicality of describing and differentiating terrain classes on statistically defined terms while at the same time supplying maximum information on physical properties.

POSSIBLE GAUSSIAN COMPONENTS OF ZIG-ZAG CURVES

William F. Tanner
Geology Dept., Florida State University, Tallahassee, Fla.

The distribution of elevations representing a region can be shown conveniently as a cumulative frequency curve plotted on probability paper. If such a distribution is, either directly or by means

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During the last decade a new technique of recording the characteristics of surface form has been developed. It grew from the necessity to define micromorphological characteristics during an investigation into the nature of slope form and slope evolution. Its basis is the identification, and recording on a base map, of the breaks and/or changes of slope which delimit morphological units (namely facets, which in section are rectilinear, and elements, which are smoothly curved). The method is relatively objective, since its use depends on the ability of the surveyor to identify and record breaks or changes of slope and not, as in the case of geomorphological mapping, on the identification of land form (*e.g.*, cuestas, river terraces) or of the nature of superficial deposits (*e.g.*, glacial outwash gravels, congeliturbate). The limitations of the technique are imposed by the plotting error of the base map. Depending on the object of the survey the most satisfactory scales have been found to be either at about 1:10,000 or 1:2500 (the British Ordnance Survey "Six Inch" or "Twenty-Five Inch" scales). The method has been used in mountainous and plain country in the United Kingdom and has been successfully tested in the West African arid and humid tropics. An area of about 100 square miles of the southern Pennines west of Sheffield in the United Kingdom has already been mapped.

VALUE OF LAND-FORM ANALYSIS IN STUDIES OF SEMIARID EROSION

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The analysis of quantitative topographic data by Geological Survey personnel engaged in erosion studies in semiarid areas of Western United States yielded the following relationships: (1) mean annual sediment yield from small drainage basins is related to a ratio of basin relief to length; (2) mean annual sediment yield per unit area decreases with increase in drainage area; (3) mean annual runoff from small drainage basins is related to drainage density; (4) the form of some convex hill slopes is shown by successive profile measurements to be related to surficial creep; (5) asymmetric drainage-basin development, including differences in hill-slope erosion and drainage density, is related to microclimatic variations on slopes of diverse exposure; (6) the cutting of discontinuous gullies is intimately related to a steepening of the semiarid valley floor by deposition; (7) aggradation in ephemeral streams appears to be most prevalent in reaches where the downstream increment of drainage area to channel length is relatively small; (8) stream-channel shape, expressed as a width-depth ratio, is related to the percentage of silt-clay in channel and bank alluvium; (9) downstream variations in stream-channel dimensions, independent of variations in discharge, can be related commonly to changes in the silt-clay content of channel and bank alluvium.

These relationships, most of which cannot be detected without actual measurement of terrain characteristics, suggest the effect of terrain on hydrologic variables and conversely some effects of erosion process and sediment type on terrain components.

PRELIMINARY INVESTIGATIONS OF A METHOD TO PREDICT LINE-OF-SIGHT CAPABILITIES

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Recent developments in line-of-sight communications and surveillance equipment make it desirable to analyze the geometric properties of the earth's surface which affect the operation of such equipment. A preliminary investigation has shown that predictive techniques can be used to determine the extent to which terrain features hinder lines of sight. For this analysis, consideration has been limited to equipment which has line-of-sight capabilities for 20 miles over smooth earth and to the ability to see into valleys from a specified point.

A mathematical model of terrain has been devised from which it is possible to predict the number of valleys which cannot be seen (protected valleys) at specified distances from the highest elevation within an area. Given dimensions of relief, average slope, and valley spacing for a particular area, one can construct the model by computing dimensions for other terrain factors which will affect line-of-sight. Figures for valley depth, distance between ridges and valleys, the angle a line-of-sight makes between the highest point and the lowest point, and the distance from valley to ridge along a line-of-sight result in an angle of valley entrance which is converted to a percentage of protected valleys.

This model has been tested in two areas of widely contrasted terrain, in Vermont and Arizona. Comparison of the predicted number of protected valleys with the actual number for both areas reveals that the trend of prediction follows the trend of what actually occurs.

TERRAIN MASK ANGLES

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Terrain mask-angle distributions are highly important in establishing the requirements and capabilities of several types of military equipment, particularly those which depend on line-of-sight. To demonstrate the feasibility of obtaining such distributions to required accuracy on a wide scale by sampling techniques, such distributions were generated for terrain in a 30 by 60 mile area in Pennsylvania.

OBJECTIVE FIELD SAMPLING OF TERRAIN PROPERTIES

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Objective, quantitative terrain analysis useful in military and engineering applications measures purely physical properties of the ground surface relevant to the given problem. To evaluate ease of dispersed cross-country movement on foot or in vehicles, an element of ground surface may be analyzed in terms of resistive forces set up by ground slope, surface roughness, soil weakness, and vegetation. Inhibition of movement depends upon the sum of these resistive forces weighted on a performance basis.

A summer field sampling program in central Maine provided data on mean values and variances for within-area and between-area analysis of three basically different terrain types with a wide range in geological properties: (1) bouldery thin till on granitic bedrock with hardwood forest, (2) bog on clay with hemlock forest, and (3) sand plain with pine forest. Roughness, or microrelief, was sampled on random 100-foot transit lines with a logarithmically scaled level rod, measuring all height differences greater than 0.1 foot. Resistance of surficial soil to shearing was sampled uniformly along these sight lines by a Corps of Engineers cone penetrometer. Determinations of remolding index, bulk density, field moisture content, organic content, and grain-size distribution provided additional soil data. Trunk diameters and tree frequency were measured in 40-foot sample circles located by random azimuths and distances. Significant differences exist in means or variances between areas, suggesting the practicality of describing and differentiating terrain classes on statistically defined terms while at the same time supplying maximum information on physical properties.

POSSIBLE GAUSSIAN COMPONENTS OF ZIG-ZAG CURVES

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The distribution of elevations representing a region can be shown conveniently as a cumulative frequency curve plotted on probability paper. If such a distribution is, either directly or by means

of a suitable transformation, Gaussian, it can be made to approximate a straight line. Many elevation distributions are not, however, Gaussian; instead, they are "zig-zag" curves such as Pearson identified among his numbered types.

The common zig-zag curve can be separated into components, three of which appear clearly in many instances: uplands, slopes, and lowlands. Some curves are more complex. In general, the separation is easy to make, with no information other than that contained in the curve.

Because the distribution is, commonly, not Gaussian, it can be represented by the use of measures of skewness and kurtosis. A plot of skewness *versus* kurtosis permits the recognition of six major forms, with countless gradations.

Analysis of approximately 100 regions from various parts of the world shows that most of them fit into what Davis would have called late maturity or old age.

DETERMINATION OF SPATIAL RELATIONSHIPS OF LOCALLY DOMINANT TOPOGRAPHIC FEATURES

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The importance, nature, and relationships of terrain compartments are analyzed, and means devised to select and measure objectively those which are especially significant in any given region. Selection is based on (1) Gutersohn's concept of a limiting distance beyond which relief no longer increases at a significant rate, and (2) consideration of the distance at which terrain exerts an influence on day-to-day human activities in areas with relief of various dimensions.

The method of measurement consists of choosing representative high and low points in the terrain. The points chosen are points of first tangency of large imaginary rising and descending spheroids. The horizontal and vertical spacing of the points give representative grain and relief. The principle is first explained in three dimensions. Then a practical method of graphical estimation is presented which uses only two dimensions at any one stage. Examples of graphical procedure are given, together with maps made by this method.

HYDROELECTRIC POWER IN THE GREAT LAKES-ST. LAWRENCE BASIN

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Some of the finest water-power sites in the world are in the Great Lakes-St. Lawrence Basin. One of the most attractive of these sites lies in the Niagara River section. Here, within a few miles, is a total concentrated fall of about 325 feet and a high river flow maintained with remarkable uniformity as a result of the regulatory effect of lakes Superior, Michigan, Huron, and Erie. Other outstanding sites are located in the several rapids sections of the St. Lawrence River and have the further benefit of the added regulatory effect of Lake Ontario. Here the heads developed are not so great as on the Niagara, but the sustained high flow of the river justifies large generating plants.

Water power in the Great Lakes-St. Lawrence Basin comes from (1) streams tributary to the lakes, (2) the interconnecting channels of the lakes (the St. Marys and Niagara rivers), (3) the St. Lawrence River, and (4) the streams tributary to the St. Lawrence River.

With the completion in November 1959 of the U. S. portion of the International Rapids Project and the redevelopment of the Niagara River, scheduled for completion in April 1962, the Great Lakes-St. Lawrence Basin within the United States will have installed hydroelectric generating capacity totaling about 4.2 million kilowatts (about 14 per cent of the total hydroelectric capacity presently in service in the United States). The total hydroelectric potential of the Great Lakes drainage area in the United States (about 5½ million kilowatts) constitutes about half the total potential of the area of the eight States involved.

NEW METHODS OF QUANTITATIVE GEOMORPHOLOGY USED AT THE CENTRE DE GEOGRAPHIE APPLIQUÉE, STRASBOURG, FRANCE

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The Centre de Geographie Appliquée at Strasbourg utilizes a quantitative approach to the evolution of drainage basins in connection with its studies for hydraulic design of dams. Results of experimentation with small-scale models left much to be desired in the case of alluvial valleys, particularly if these valleys were vegetated.

Studies applicable both to hydraulic and agricultural problems were therefore initiated to show what happens in the bed of water courses and their catchment areas, particularly during exceptional floods. The following methods have been applied successfully very recently to the Alpine basin of Guil: (1) Detailed geomorphologic mapping of the basin at a scale of 1:20,000 and of the valley bottoms at a scale of 1:5000 based on field observation and aerial photographs. From this study are derived such catchment-area parameters as density of gullies, extent of erosion, disposition of the alluvial strata, arrangement of the torrential streams with respect to lithology, the character of the vegetation blanket, slopes, etc. (2) Torrential streams are studied at stations spaced not more than 2–3 km apart with respect to the petrographic composition of the bed material, the grading of this material, shape of the gravel, median grain diameters, etc. (3) The over-all composition of the alluvium is computed with respect to the percentages of various characteristic sizes observed and to the over-all grading curve. It is subsequently compared with the lithologic composition of the basin alluvium, which permits determination of a coefficient of erosion for areas of varying lithology. Correlation of these data permits determination of the part played by the various morphogenetic factors in the evolution of the basin.

SURFACE AND GROUND-WATER SUPPLIES IN ONTARIO

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Ontario, with an area of 412,502 square miles, has a variety of geological conditions which are mainly responsible for a considerable range in the quality and quantity of its water supplies. However, more than 90 per cent of Ontario's 6 million people live in Southern Ontario, where most of the populated areas lie within 50 miles of one of the Great Lakes.

Although, generally speaking, existing sources of supply are adequate for present needs, rapid residential and industrial development since 1945 has precipitated many problems of water supply.

A committee appointed by the provincial government in 1955 to investigate and advise on water-supply problems led to the formation of a Water Resources Commission in 1956, which has been given broad authority over water supply and pollution in Ontario.

Since 1957, agreements have been entered into with 39 municipalities to finance and construct water works costing $9,964,000. Fifteen projects were in operation by September, 1959.

Municipal water-works systems totalled 419 at the end of 1958, serving 77 per cent of the population of the province. About 30 per cent of the population use ground water.

Water-supply conditions are poorest in those counties adjoining Lake Erie and parts of Lake Huron and Lake Ontario. A 3.7-million-dollar pipe line was put into operation in August 1958. Additional pipe-line projects are under consideration. The cost of piping Great Lakes water to the inland communities in Southern Ontario is the main deterrent at the present for many municipalities with water-supply problems.

TERMINATIONS OF PASSAGES IN APPALACHIAN CAVES AS EVIDENCE FOR A SHALLOW PHREATIC ORIGIN

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Considerable controversy exists between advocates of the deep phreatic theory of cave origin of Davis and Bretz and advocates of the shallow phreatic theory of Davies and Sweeting. The deep phreatic theory predicts cavern enlargement along any open conduit in a lithologically suitable bed without regard to depth below the water table. The shallow phreatic theory predicts solution only in a limited zone just below the water table. The latter theory was supported by evidence found in the examination of about 25 caves in the Appalachian Mountains.

Caves with maze patterns have apparently formed by slow phreatic flow along a soluble bed. In flat-lying limestone, caves with this pattern may have considerable area, but in strata of medium dip, passages on the updip and downdip sides terminate abruptly. Hence solution is limited to a narrow zone, even though the soluble bed continues in both directions. Several caves in nearly vertical limestone have been examined. In none of these had solution extended any distance along the bedding in a vertical direction, even though a favorable bed and good partings existed in that direction. Instead the caves are limited to a nearly horizontal zone. Cross sections of caves in steeply dipping limestone show that the passages tend to be elongated along layers of good solubility. In the updip direction the cross section narrows and pinches out. In the few caves where the cross section can be traced downdip, the same thing is observed.

These data show that caves tend to maintain their horizontal pattern in spite of structure and lithology. The position of the water table is apparently the dominant controlling factor; structure and lithology seem merely to modify the ground plan and passage cross section.

PREDICTION IN TERRAIN ANALYSIS

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In the development of a science, order is first discovered; then it is defined and quantified, and finally the knowledge gained is used to predict or control. At any stage of growth, new sciences may bud off and follow their more or less independent course. It now appears that the roots of quantified terrain analysis are in modern hydrology.

In 1802 Playfair discovered the order and stated its nature in his now famous Law of Concordant Stream Junctions. In 1945, Horton presented his interpretation of Playfair's Law and thus defined the order and quantified it. In essence, the work of Horton and subsequent workers demonstrated that dimensions of stream basins of different orders have fixed relationships to each other, usually geometric.

Workers at the Quartermaster Research and Engineering Center have shown that hydrologic laws also apply to randomly chosen samples of terrain sharing a common center. This led to the development of predictive methods based on probability. Relief, slope, or other dimensions are predictable for small areas from information about the larger areas in which they are contained. The division of samples into separate and more homogeneous populations, on the basis of bedrock or vegetation, results in better predictions.

CHARACTERISTIC AND LIMITING SLOPE ANGLES

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Previous work on slope development has suggested that certain angles have particular significance. Two related concepts are found. Characteristic slope angles are defined as those angles which most frequently occur either on all slopes, under particular conditions of rock type or climate, or in a local

region. Limiting slope angles show the range within which particular types of ground surface occur, or particular denudational processes operate. Data from 30 surveyed slope profiles, in 3 areas of Britain, are presented in graphical form, showing the frequency of occurrence of slopes at each half-degree angle. In each area the peak frequencies are related to local morphological history and are not intrinsic features of slope development. An exception to this is a peak of 25°–29°, which is found in all three areas. Evidence is presented indicating that the limiting angle for a slope possessing a smooth soil and vegetation cover, without scars or terracettes, is slightly below 32°. It is assumed that the presence of such ground-surface features indicates relatively rapid slope retreat. Therefore, following a period of steepening of slopes consequent upon river erosion, the slope at 25°–29° is the first slope to be formed which retains its angle for a relatively long period of time.

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TREATISE ON INVERTEBRATE PALEONTOLOGY

Raymond C. Moore, *Editor*

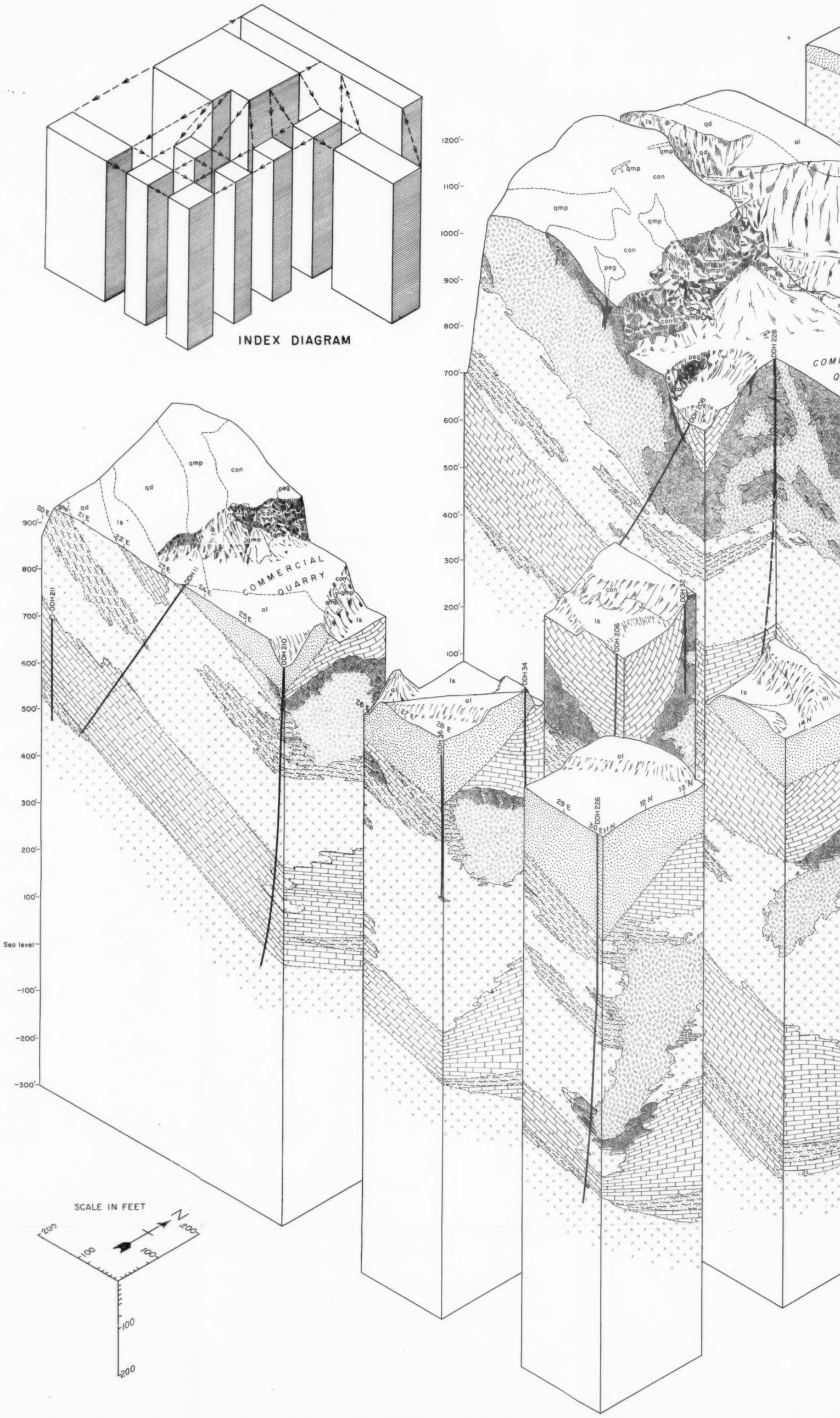
Part D. Protista 3. Chiefly Radiolarians and Tintinnines). By A. S. Campbell and R. C. Moore. 1955. 195 p., 93 figs. $3.00.
Part E. Archaeocyatha and Porifera. By V. J. Okulitch and M. W. de Laubenfels. 1955. 123 p., 78 figs. $3.00.
Part F. Coelenterata. By F. M. Bayer *et al.* 1956. 498 p., 358 figs. $7.00.
Part G. Bryozoa. By Ray S. Bassler. 1954. 253 p., 175 figs. $3.00.
Part L. Mollusca 4 (Cephalopoda; Ammonoidea). By W. J. Arkell *et al.* 1957. 490 p., 558 figs. $8.50.
Part O. Arthropoda 1 (Trilobitomorphs). By 18 authors. 1959. 560 p., 415 figs. $10.50.
Part P. Arthropoda 2 (Chelicerata, Pycnogonida, Palaeoisopus). By L. Störmer, A. Petrunkevitch, J. W. Hedgpeth. 1956. 181 p., 123 figs. $3.50.
Part V. Graptolithina. By O. M. B. Bulman. 1955. 101 p., 72 figs. $3.00.

SPECIAL PAPERS

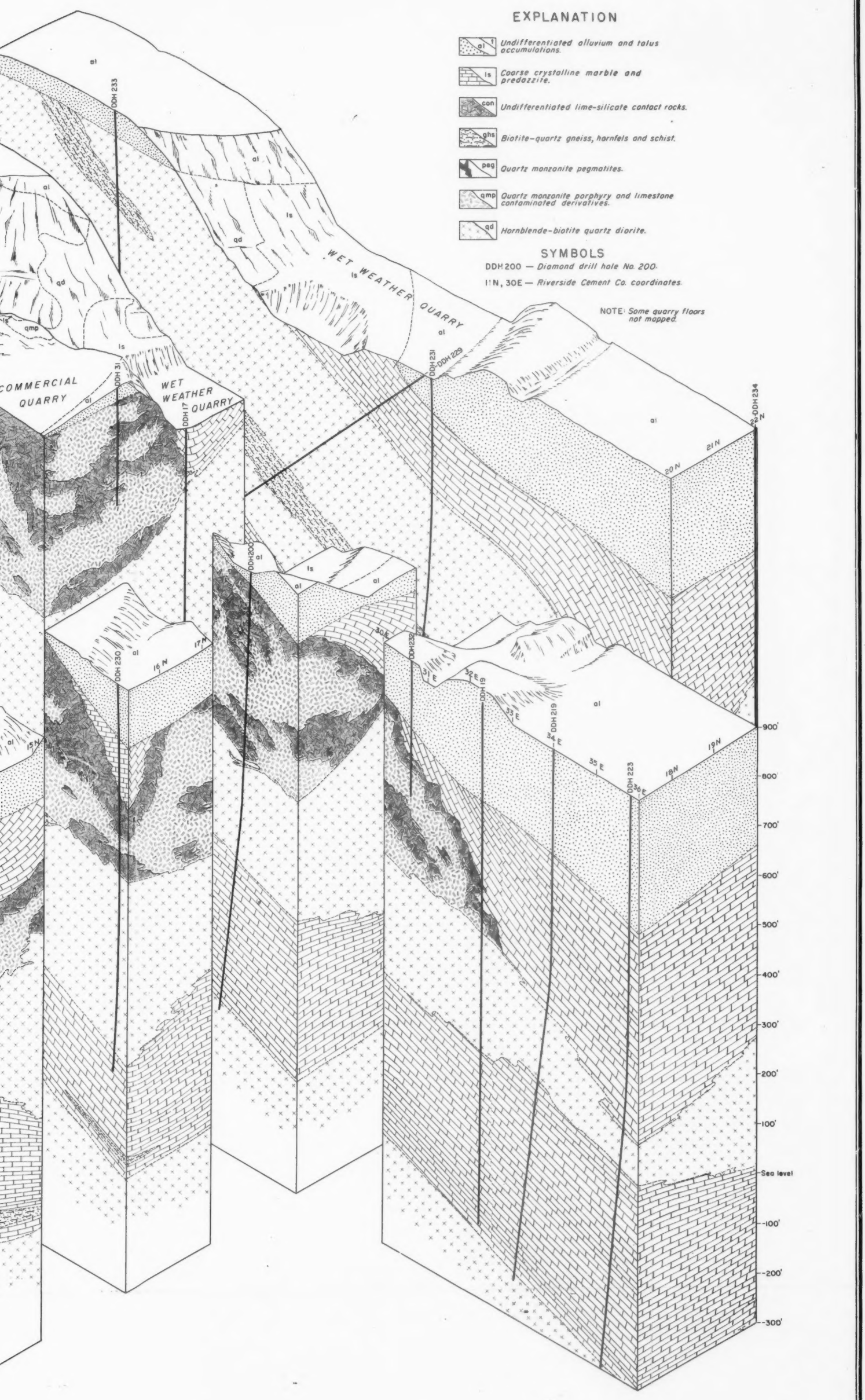
1. Bibliography and Index of Paleozoic Ostracoda. R. S. Bassler and Betty Kellet. 1934, 500 p., 24 figs. $3.00.
2. Fossil Crustacea of the Atlantic and Gulf Coastal Plain. M. J. Rathbun. 1935. 160 p., 26 pls., 2 figs. $1.50.
3. Fossil Non-Marine Mollusca of North America. Junius Henderson. 1935. 313 p. $2.10.
5. Geology of Saint John, New Brunswick. A. O. Hayes and B. F. Howell. 1937. 146 p., 9 pls., 4 figs. $1.50.
7. Atlantic Submarine Valleys of the United States and the Congo Submarine Valley. A. C. Veatch and Phil A. Smith. 1939. 101 p., 5 charts, 10 pls., 28 figs. $4.00.
9. Fossil Snakes of North America. C. W. Gilmore. 1938. 96 p., 4 pls., 38 figs. $0.90.
11. Geology and Paleontology of the Mingan Islands, Quebec. W. H. Twenhofel. 1938. 132 p., 24 pls., 1 fig., $1.50.
12. Tertiary Flora from the Rio Pichileufu, Argentina. E. W. Berry. 1938. 149 p., 56 pls., 11 figs. $2.10.
21. Paleontology and Stratigraphy of the Silurian Rocks of the Port Daniel Black Cape Region, Gaspe. A. O. Northrop. 1939. 202 p., 28 pls., 1 fig. $3.00.
28. Review of the Pelycosauria. A. S. Romer and L. I. Price. 1949. 538 p., 46 pls., 71 figs. $4.20.
29. Phacopid Trilobites of North America. D. M. Delo. 1940. 135 p., 13 pls., $1.20.
33. Numerical Structure Factor Tables. M. J. Buerger. Reprinted 1953. 119 p., 4 figs. (Cloth bound) $1.50.
37. Ozarkian and Canadian Cephalopods, Part I, Nautilicones. E. O. Ulrich, Aug. F. Foerste, A. K. Miller and W. Furnish. 1942. 157 p., 57 pls., 23 figs. $2.40.
40. Hadrosaurian Dinosaurs of North America. R. S. Lull and N. E. Wright. 1942. 242 p., 31 pls., 90 figs. $3.75.
48. North American Pleospongia. V. J. Okulitch. 1943. 112 p., 19 figs. $1.50.
49. Ozarkian and Canadian Cephalopods. Part II: Bevicones. E. O. Ulrich, A. F. Foerste, and A. K. Miller. 1943. 226 p., 70 pls., 15 figs. $3.00.
60. Glacial Map of North America. By Committee on Glacial Map. R. F. Flint, *Chairman*. 1945. $3.00.

(*Continued on inside back cover*)

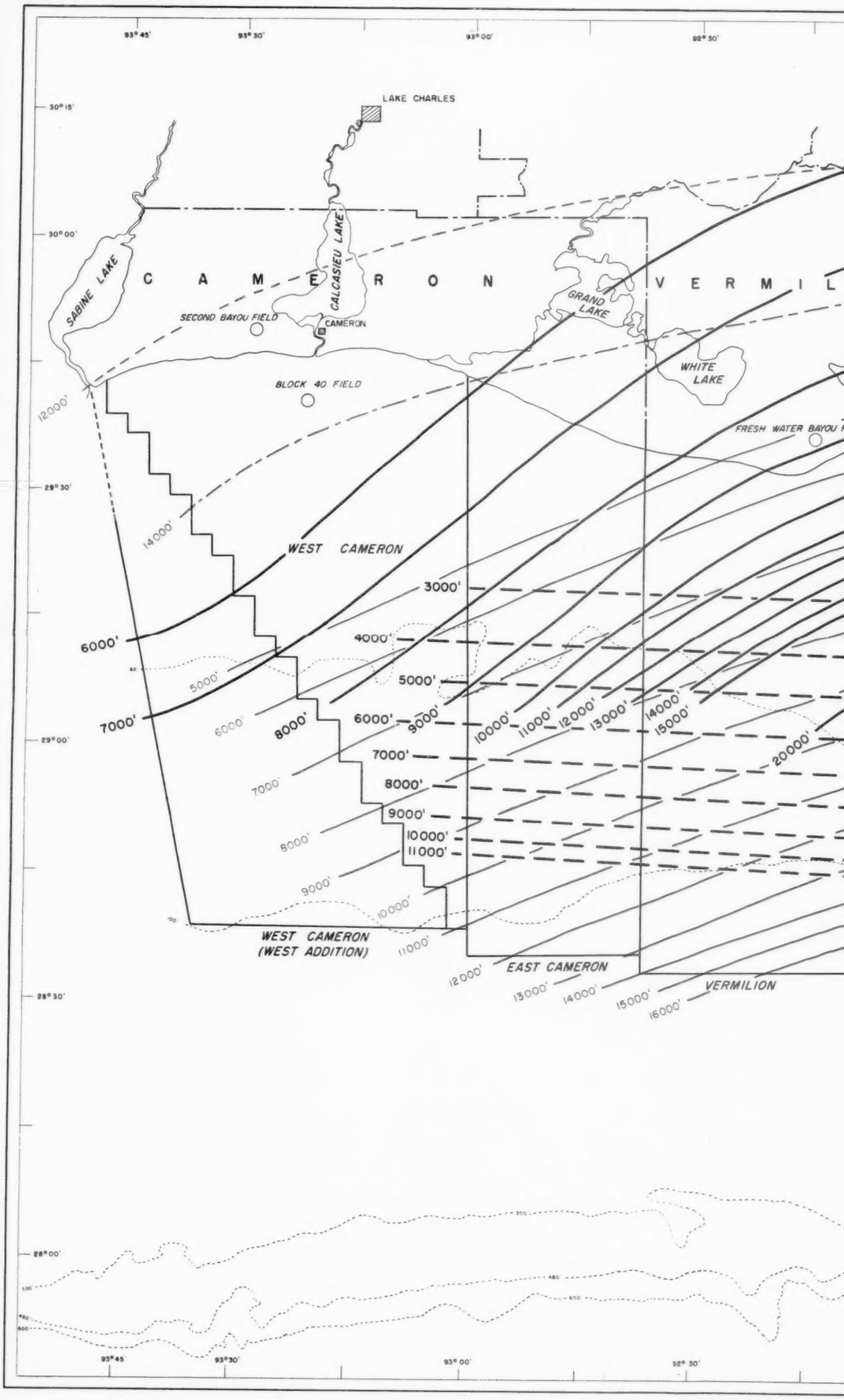
INDEX DIAGRAM



EXPLODED ISOMETRIC BLOCK DIAGRAM OF THE COMME



MERCIAL QUARRY, CRESTMORE, CALIFORNIA


93° 45'
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30° 00'
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28° 30'
28° 00'
LAKE CHARLES
SABINE LAKE
CALCASIEU LAKE
C A M E R O N
V E R M I L
SECOND BAYOU FIELD
CAMERON
GRAND LAKE
WHITE LAKE
BLOCK 40 FIELD
FRESH WATER BAYOU
WEST CAMERON
WEST CAMERON (WEST ADDITION)
EAST CAMERON
VERMILION
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14000'
3000'
4000'
5000'
6000'
7000'
8000'
9000'
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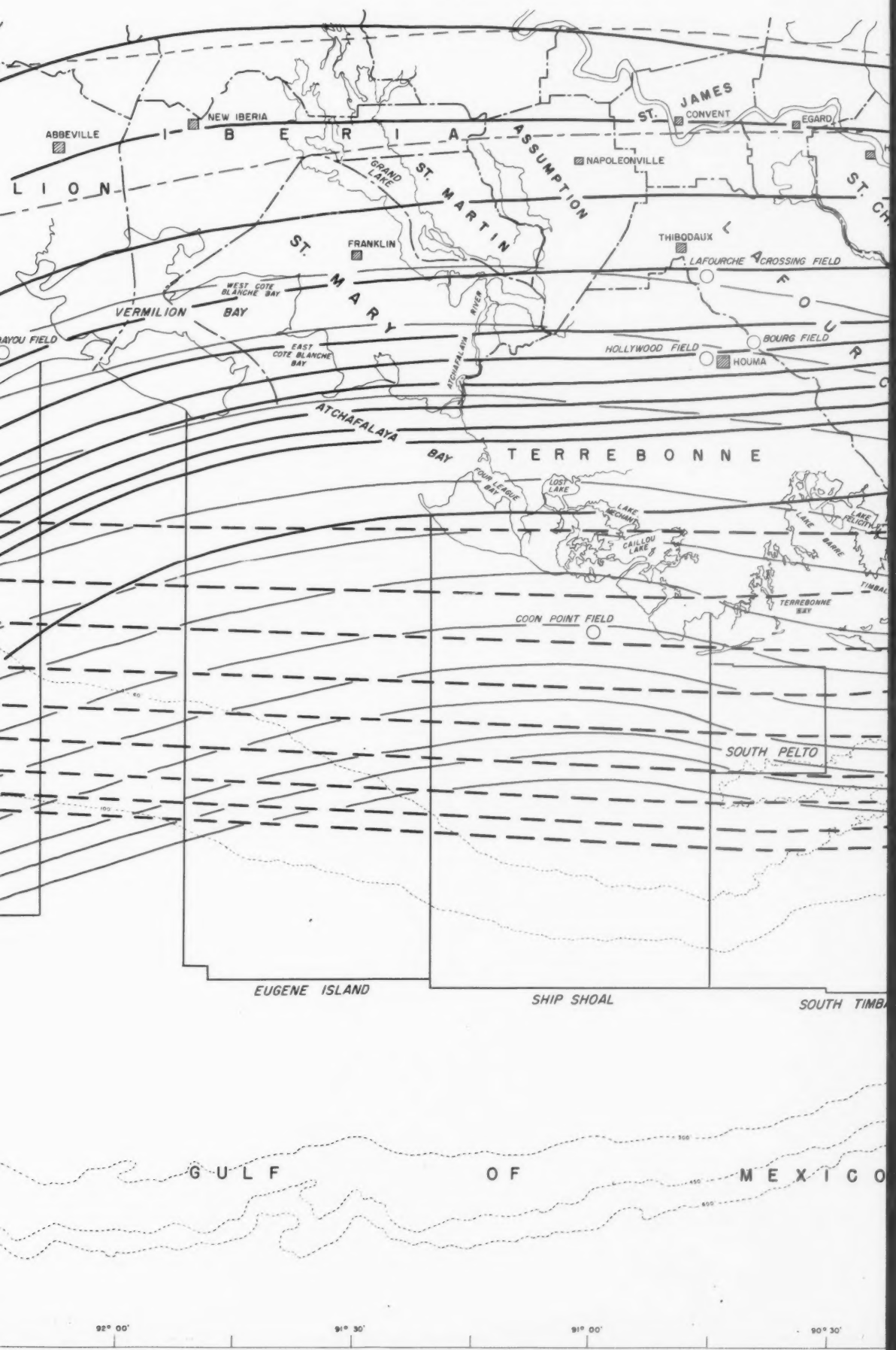
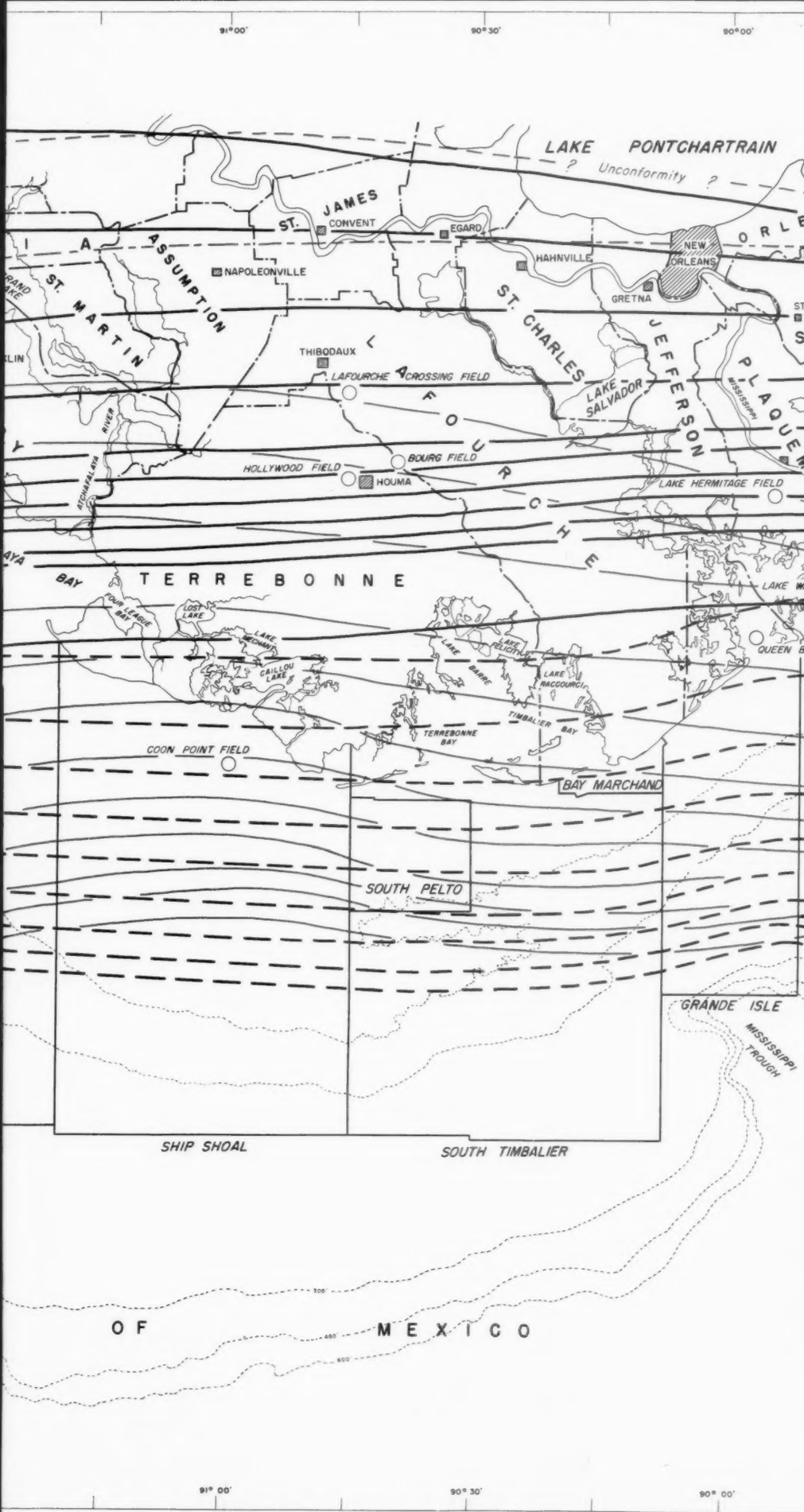
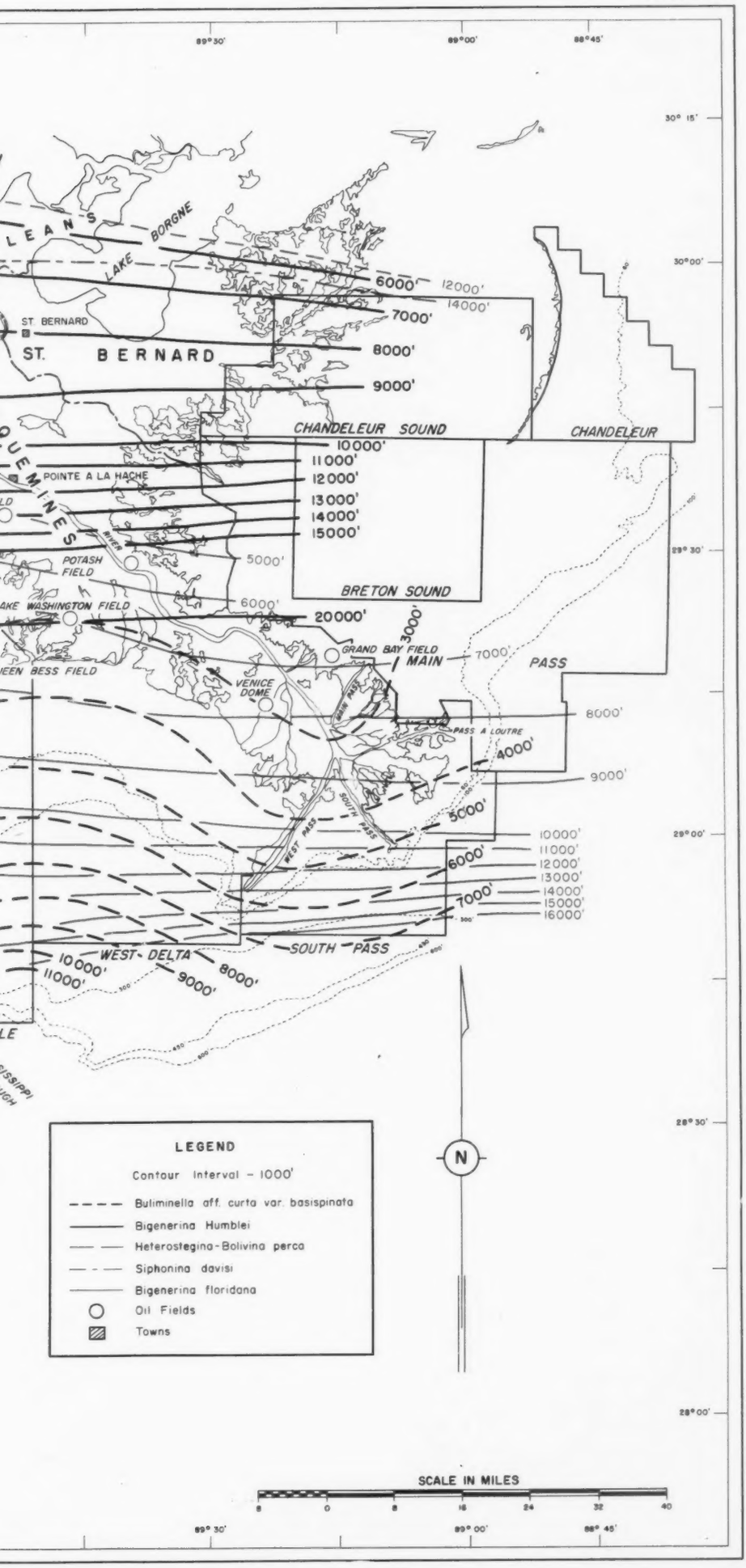
11000'
12000'
13000'
14000'
15000'
16000'
20000'



CONTOUR MAP OF SOUTHERN LOUISIANA AND OFFSHORE AR



ERN LOUISIANA AND OFFSHORE AREA


89° 30'
89° 00'
88° 45'
30° 15'
30° 00'
29° 30'
29° 00'
28° 30'
28° 00'
LAKE BORGNE
ST. BERNARD
ST. BERNARD
POINTE A LA HACHE
POTASH FIELD
LAKE WASHINGTON FIELD
QUEEN BESS FIELD
CHANDELEUR SOUND
CHANDELEUR
BRETON SOUND
GRAND BAY FIELD
MAIN PASS
VENICE DOME
PASS A LOUTRE
WEST PASS
SOUTH PASS
WEST DELTA
6000'
12000'
14000'
7000'
8000'
9000'
10000'
11000'
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13000'
14000'
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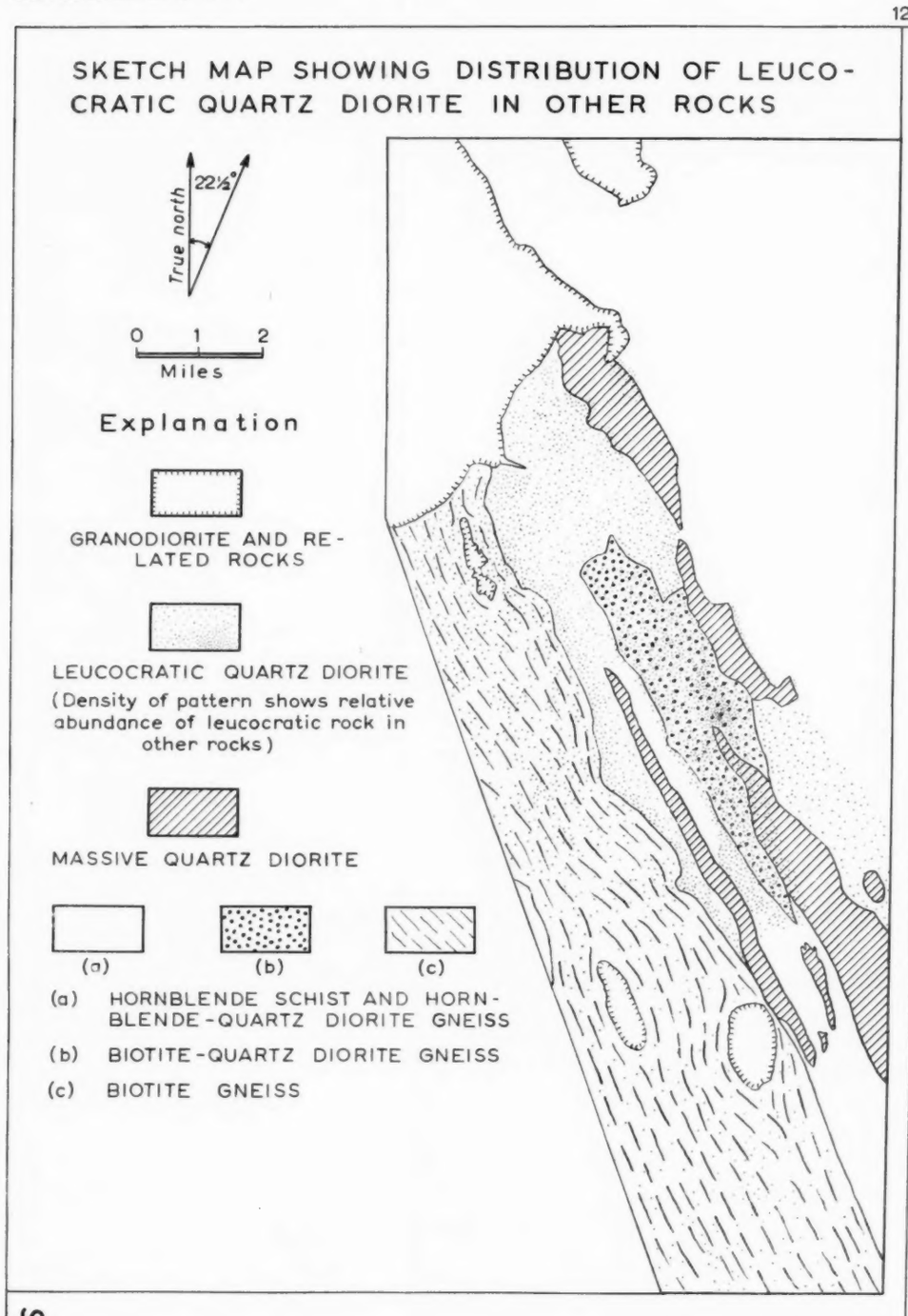
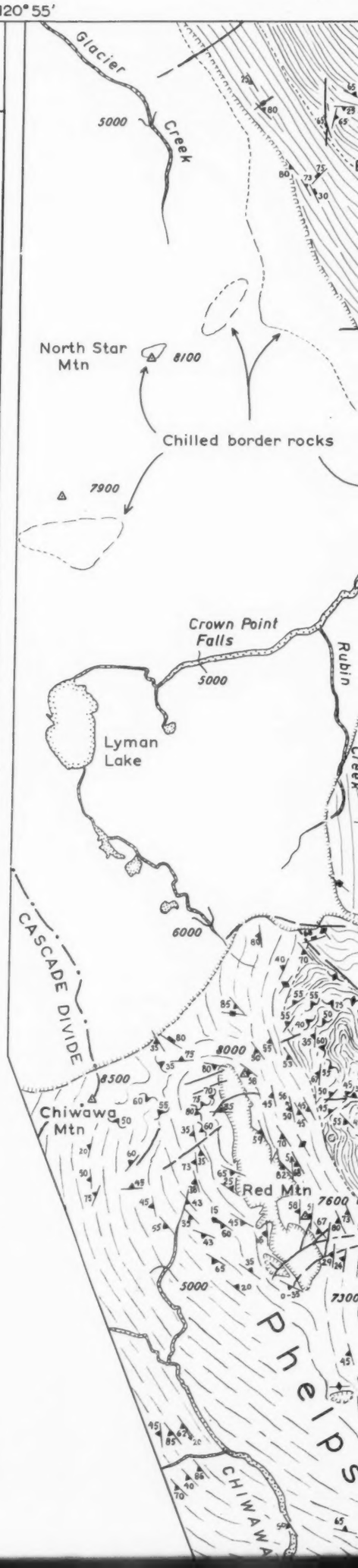
11000'
6000'
12000'
13000'
7000'
14000'
15000'
16000'
10000'
11000'
8000'
9000'
LEGEND
Contour Interval - 1000'
Buliminella aff. curta var. basispinata
Bigenerina Humblei
Heterostegina-Bolivina perca
Siphonina davisi
Bigenerina floridana
Oil Fields
Towns
N
SCALE IN MILES
8 0 8 16 24 32 40





EXPLANATION

POST-EOCENE ROCKS

DIKE

GRANODIORITE WITH CHILLED BORDER OF PORPHYRITIC—APHANITIC ROCKS; RELATED DIKES, PLUGS, AND INTRUSIVE BRECCIAS

EOCENE ROCKS

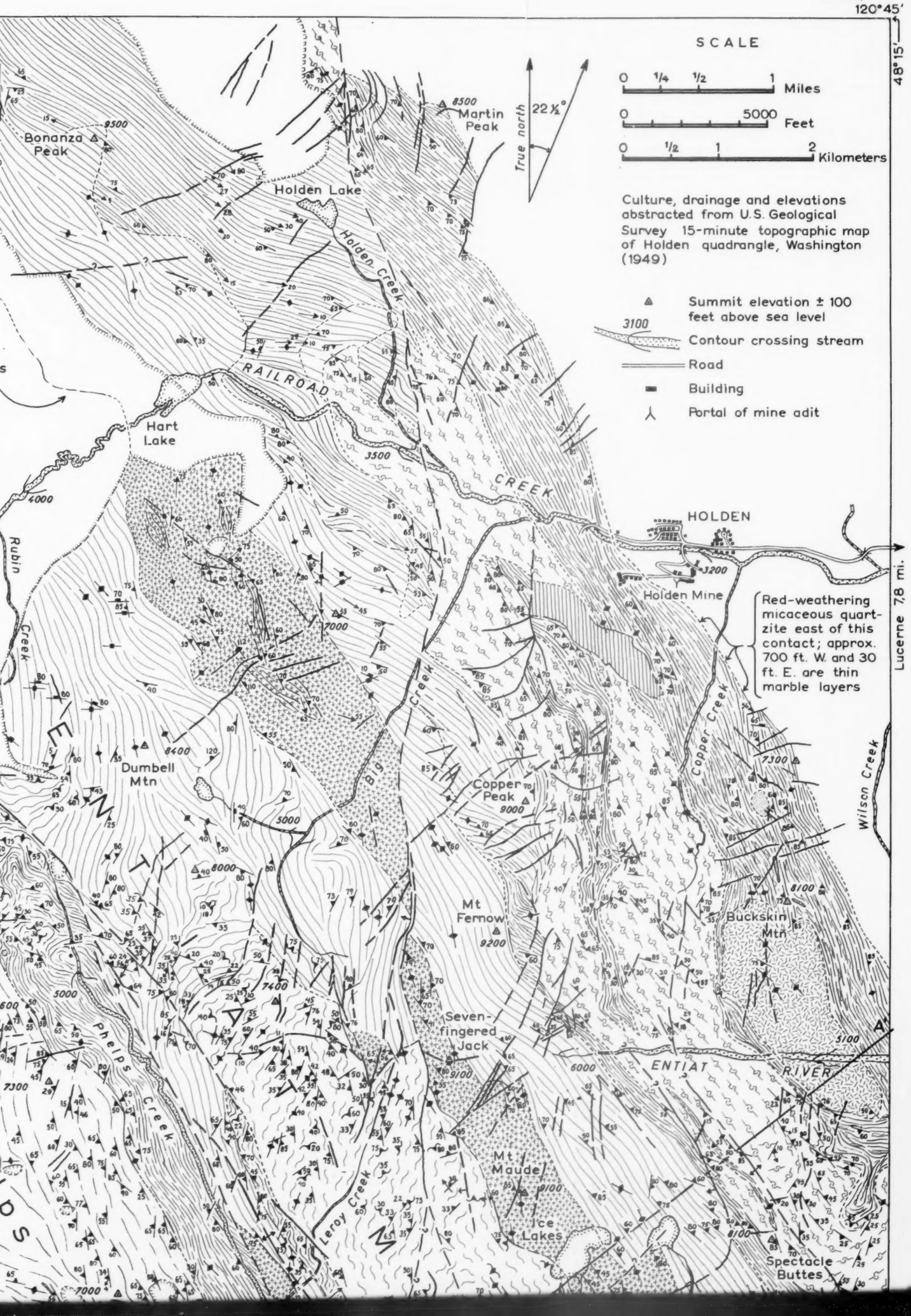
SWAUK FORMATION

Conglomerate, grit, sandstone; a few thin coal seams.

STOCKS AND DIKES

(A) (B) (C) (D) (E)

(A) BIOTITE-QUARTZ DIORITE GNEISS
(B) FINE-GRAINED BIOTITE GRANODIORITE


120°45'
48°15'
SCALE
0 1/4 1/2 1 Miles
0 5000 Feet
0 1/2 1 2 Kilometers
True north 22½°
Culture, drainage and elevations abstracted from U.S. Geological Survey 15-minute topographic map of Holden quadrangle, Washington (1949)
Summit elevation ± 100 feet above sea level
Contour crossing stream
Road
Building
Portal of mine adit
Red-weathering micaceous quartzite east of this contact; approx. 700 ft. W. and 30 ft. E. are thin marble layers
Lucerne 7.8 mi.
Bonanza Peak
Martin Peak
Holden Lake
Holden Creek
RAILROAD
Hart Lake
CREEK
HOLDEN
Holden Mine
Rubin Creek
Dumbell Mtn
Big Creek
Copper Peak
Copper Creek
Wilson Creek
Mt Fernow
Buckskin Mtn
Seven-fingered Jack
ENTIAT RIVER
Phelps Creek
Leroy Creek
Mt Maude
Ice Lakes
Spectacle Buttes
A
A'

EOCENE ROCKS

PRE-EOCENE ROCKS

SWAUK FORMATION

Conglomerate, grit, sandstone; a few thin coal seams.

STOCKS AND DIKES

(A) (B) (C) (D) (E)

(A) BIOTITE-QUARTZ DIORITE GNEISS
(B) FINE-GRAINED BIOTITE GRANODIORITE
(C) ULTRAMAFIC ROCKS (HORNBLENDITE AND PERIDOTITE)
(D) HORNBLENDE GABBRO AND DIORITE
(E) MAFIC DIKES

} In part older than rocks of the complex

ROCKS OF THE COMPLEX

Swarm of inclusions

(5) (6)

MASSIVE QUARTZ DIORITE

(5) Biotite - hornblende - quartz diorite
Western mass badly sheared and gneissic

(6) Hornblende - biotite - quartz diorite
Some granodiorite phases

(8) (2) (3) (4)

QUARTZ DIORITE GNEISS

(8) Biotite - quartz diorite gneiss
Swirled foliation very common.

(2) Well-foliated hornblende - quartz diorite gneiss
Fine medium-grained. Foliation not swirled.

(3) Granitoid hornblende - quartz diorite gneiss
Medium-grained, swirled foliation and massive phases common.

(4) Hornblende - quartz diorite augen gneiss
Augen and streaks of quartz and swirled foliation common.

(a) (b) (A) (B)

MIGMATITE IN HORNBLENDE SCHIST

(A) Recrystallization type
(a) Clots of hornblende and seams and dikes of hornblende-quartz diorite and diorite
(b) Heterogeneous mixtures of massive fine-grained to pegmatitic hornblende diorite

(B) Replacement type
Streaks of fine-grained light-colored hornblende-biotite-quartz diorite parallel to foliation of hornblende schist

PRE-COMPLEX ROCKS

(1) (7)

(1) HORNBLENDE SCHIST AND GNEISS

Highly variable ratio of hornblende to light colored minerals

(7) BIOTITE GNEISS

Typically almost schistose, well segregated into light and dark layers and wisps in migmatites, garnet-bearing phases common

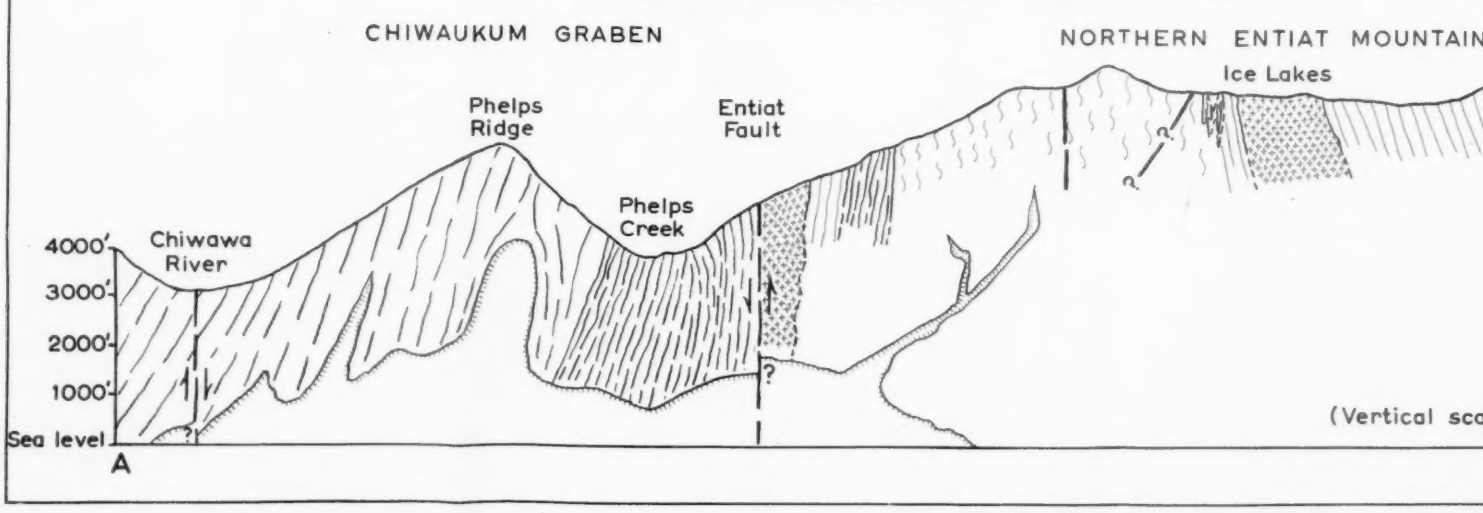
STRUCTURE SYMBOLS

- Contact (Dashed where approximately located)
- Indefinite or gradational contact
- Fault showing dip (Dashed where approximate located)
- Probable fault
- U / D — Fault showing relative m; U upthrown block, D dow block
- 30 — Strike and dip of bedding
- 10 — Strike and dip of foliatio
- Strike of vertical foliatio
- Horizontal foliation
- Generalized strike and di
- Generalized strike of vert
- 20 — Bearing and plunge of ho or mineral streaks
- 20 — Strike and dip of joints
- Strike of vertical joints

GEOLOGY
D.F. CROWDER, F.W. CATER, C.A. HO
R.W. TABO
(1950 - 195
Drawn by Ingri

NUMBERS OF ROCK UNITS COR
NUMBERS IN TABLE 5

CROSS SECTION ALONG A-A'



GEOLOGIC MAP OF THE NORTHER

na-

nal

nately

e movement
downthrown

lding

ation

iation

d dip of swirled

vertical swirled foliation

f hornblende prisims

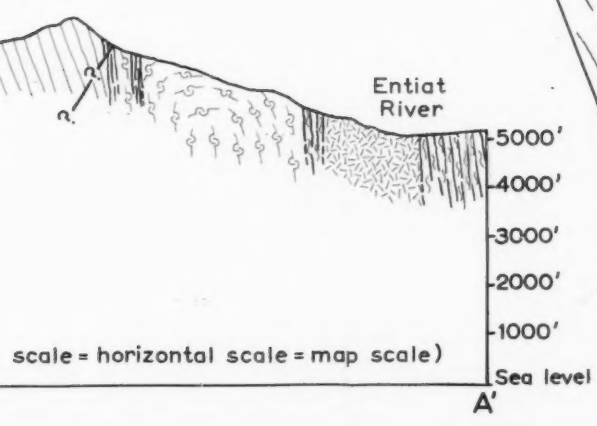
ts

nts

GY BY
A. HOPSON, D.F. KELLUM and
ABOR
-1955)
grid Lowzow

CORRESPOND TO ROCK ANALYSIS

TAINS



scale = horizontal scale = map scale)

IERN ENTIAT MOUNTAINS, WASHINGTON

1
2
3
4
5
6
7
116° 15'
35° 25'
AVAWATZ MOUNTAINS
(southern end)
California Institute of Technology
Vertebrate Fossil Location 267
Tau
1800
500
A
B
C
D
E
F
G
H
I
J
K
Tau
BM 1606
BM 1361
?
35° 22' 30"
Qal
Msv?
2200'
2600'
1800
Range
35° 20'
Tau
BM 1506
Qal
C
?
Mss
Msv
Msv
BM
1271
Spectre
Spur
B
Msv
Msv
Msv
Mss
Msv

7 8 9 10 11 12 13 14

116° 12' 30" 116° 10' 116° 7' 30"

Dolomite Mountain

Talc △ 929

Tfu

BM 989

BM 938

BM 876

BM 937

A A'

B B'

D D'

Quartzite Hills

SILVER

Lakeshore Hill

Target Flat

Qp Qal Taf Tas Msv

qd gr bc cu pu m gd pgd

ϵp_1 ϵp_2 ϵp_3 ϵs $p\epsilon m$

6 7 8 9 10 11 12 13

116° 12' 30" 116° 10'

NTAINS
d)

Dolomite
Mountain

BM 938

BM 989

BM 876

BM 937

Quartzite
Hills

Spectre
Spur

Target
Flat

Qal

Qp

Tfu

Taf

Tos

qd

gr

bc

cu

pgd

gd

m

Mss

Msv

A

A'

C

14 15 16 17 18

116° 7' 30" 116° 5'

35°25'

Talc
929

pu
cu

SILVER LAKE
CAMP
Qal

pu
cu
pu
cu
cu

pu

35°22'30"

Qp

SILVER LAKE

BM 909

121

SILVER

LAKE

BM 933

B'

Airport
BM
920

PLAYA

BM 907

gr

35°20'

Lakeshore
Hill

Qp

BM
924

D'

Range

Red Pass

Spectre Spur

FAULT

WEST

FAR

BM 1506

BM 1685

BM 1834

BM 2015

BM 1271

35°20'

35°17'30"

35°15'

116°15'

Red Pass Lake 15' Quad. Baker Quad

Cave Mountain Quad Soda Lake Quad

Qal

Tau

Tou?

Tqs

Msv?

Msv

Mss

Mis

Phl

Pbs

Mqm

Mqd

Msv-t

Ti

Mmi

Planimetry from air photographs by multiplex mapping

Topography from Baker, Soda Lake, Cave Mountain, and Red Pass Lake USGS Quadrangle maps

BM 937

B'

D'

F'

Lakeshore Hill

Target Flat

SODA-AVAWATZ FAULT ZONE

WEST GRANITE RIDGE FAULT

EAST FAULT

Moonshine Area

Highway Spur

Jeep

VABM 3437

Soda Mtn

USMM 53 Blue Bell Mine

VABM 2849

Qal

Taf

Tas

Taf?

Tag

Tfu

Msv

Mls

Mqm

Mgr

Mqd

Mss

Phl

Mmi

gd

gd?

pgd

gr

m

pC$_1$

pC$_2$

pC$_3$

pCm

pCs

pCg

qd

bc

cu

cu?

ls

2800

3000

3200

Range

Red Pass

Spectre Spur

F.A.R.W.E.S.T.

BM 1506

BM 1271

BM 1685

BM 1834

BM 2015

Tou

Qal

Msv

Mss

Pbs

Phl

Mls

Mqm

Mqd

Mmi

Tqs

Tou?

35°20'

35°17'30"

35°15'

116°15'

Red Pass Lake 15' Quad Baker Quad
Cave Mountain Quad Soda Lake Quad

Planimetry from air photographs by multiplex mapping

Topography from Baker, Soda Lake, Cave Mountain, and Red Pass Lake USGS Quadrangle maps

B'

D'

F'

Lakeshore Hill

Target Flat

Jeep Highway

Spur

SODA-AVAWATZ FAULT ZONE

WEST FAULT

FAULT

Granite Ridge

Mormonite Area

Soda Mtn.

VABM 3437

BM 937

1000

1200

1400

1600

1800

2000

2200

2800

3000

3200

BM 937
BM 1271
Spectre Spur
Target Flat
SODA-AVAWATZ FAULT ZONE
WEST
Granite Ridge
FAULT
Soda Mtn
VABM 3437
USMM 53
VABM 2849
Blue Bell Mine
Mohnstine Area
Qal
Taf
Tas
Mss
Msv
Mls
Mqm
Pbs
Phl
Mgr
Mqd
Mmi
Tag
Tfu
p€m
p€g
gr
gd
pgd
bc
cu
ls
m

LAKE

PLAYA

BM 933

Airport

BM 920

BM 907

35°20'

Lakeshore Hill

Qp

BM 924

B'

D'

South Lakeshore Hill

BM 919

Qal

35°17'30"

Hopeless Hill

BAKER

BM 923

Jeep Flat

F'

G'

H'

Baker Hill

BM 923

Highway

Taf

Spur

Qal

BM 922

Tas

Msv

Mss

Taf

Msv

Mss

Mdm

Qal

pC m

pC g

gr

qd

cu

bc

Tfu

gd?

1200

1000

1600

1400

1800

C
C'
G
BM 937
BM 1271
Spectre Spur
Target Flat
SODA-AVAWATZ FAULT ZONE
WEST
EAST FAULT
Granite Ridge
Soda Mtn
VABM 3437
VABM 2849
USMM 53
Blue Bell Mine
Moonshine Area
Qal
Taf
Tas
Msv
Mss
Mls
Mqm
Mqd
Mgr
Mmi
Phl
Pbs
Ti
Ks
Tag
Tfu
Is
pgd
gd
gr
m
bc
cu
pCg
Cp1
Cp2
Cp3
Cs
pCm

LAKE

PLAYA

BM 933

Airport

BM 920

BM 907

35°20'

Lakeshore Hill

Qp

BM 924

B'

D'

South Lakeshore Hill

BM 919

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35°17'30"

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Jeep Flat

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G'

H'

BAKER

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Baker Hill

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Highway

Taf

Spur

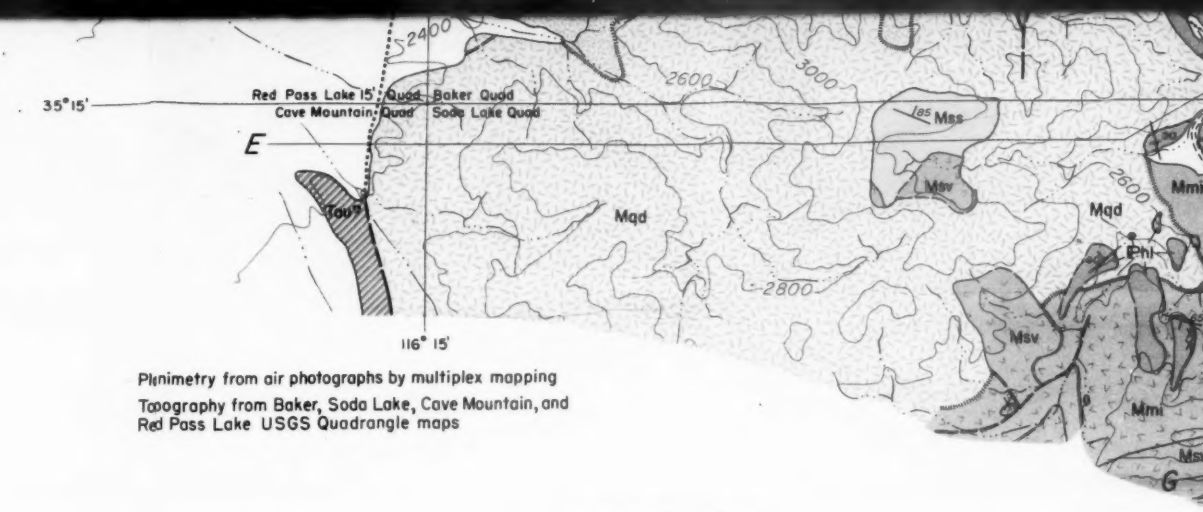
Mss

Msv

Tas

Qal

BM 922



Planimetry from air photographs by multiplex mapping

Topography from Baker, Soda Lake, Cave Mountain, and Red Pass Lake USGS Quadrangle maps

S T U V W X Y

EXPLANATION

CENOZOIC

QUATERNARY

Qal — Alluvium

Qp — Playa

TERTIARY — LOWER PLIOCENE

AVAWATZ FORMATION

Tag — Gravel, fine, poorly bedded

Tas — Sand and gravel in lenses and beds

Taf — Fanglomerate, boulder and cobble, poorly bedded

Tfu — Fanglomerate, undifferentiated. Clasts are mainly plutonics

Tou — Avawatz formation, undifferentiated

ls — Limestone breccia monolithologic

v — Andesite breccia, monolithologic, sedimentary

Ti — Felsite and felsite porphyry; dikes and plugs

MESOZOIC

CRETACEOUS

LATE MESOZOIC PLUTONICS

Mmi — Altered granitic rocks, light gray, silicified, epidotized, brecciated

Mgr — Granite with pinkish K-feldspar, coarse-grained, in part aplitic

Mqm — TEUTONIA QUARTZ MONZONITE and granodiorite, medium-grained, pinkish gray

Mqd — Quartz diorite and diorite, dark gray, fine to medium-grained, in part slightly migmatitic

PRE-TERTIARY PLUTONICS

gr — Microcline granite, white, medium to coarse-grained, uniform

gd — Granodiorite, light gray, medium-grained

m — Migmatite, small to large scale directionless mixture of pre-Tertiary plutonic types

pgd — Porphyritic granodiorite, medium to dark gray, with fine-grained groundmass

qd — Quartz diorite, dark gray, fine to medium-grained

bc — Basic complex of gabbroic and dioritic gneisses with locally more acidic migmatites

pu — Pre-Tertiary plutonics, undifferentiated

TRIASSIC-JURASSIC?

SODA MOUNTAIN FORMATION

Mss — Quartzite, sandstone and minor pyroclastics, yellow, gray, red, fine to very coarse

Msv — Meta-andesite flow breccia and minor pyroclastics, purple, gray, green, epidotized

LOWER TRIASSIC

Ts — Limestone, gray, and shale, red and gray, fossiliferous grading up into red siltstone and sandstone

CONTACT NOT EXPOSED

LOWER PERMIAN

Pbs — BIRD SPRING FORMATION, limestone, gray, thin to thick bedded, fossilliferous, cherty

THRUST FAULT

MISSISSIPPIAN-PENNSYLVANIAN?

Phl — Limestone, gray, interbedded with banded hornfels (meta-marl) and subordinate quartzite

Mls — Limestone, white to gray, massive to thin bedded, locally cherty and dolomitic

CONTACT NOT EXPOSED

PALEOZOIC

PRE-MESOZOIC METASEDIMENT

Cw — Carbonate, undifferentiated. Irregular and interbedded buff dolomite and light limestone

LOWER CAMBRIAN?

PROSPECT MOUNTAIN QUARTZITE

ϵp_3 — Quartzite, dark gray, finely laminated, cross-bedded, medium to very coarse, impure

ϵp_2 — Quartzite, white, thick bedded, medium-grained to conglomeratic, relatively pure

ϵp_1 — Quartzite, dark gray, silty; interbedded with dolomite; siliceous

ϵs — Limestone and dolomite, white, gray, buff, crystalline, locally breccia; interbedded with quartzite

THRUST FAULT

PRECAMBRIAN

PRECAMBRIAN?

p€m — Metasediment, mainly dark gray quartzite interbedded with calc-silicate layers

p€g — Gneissic complex of fine-grained paragneisses, schists, aplites, quartzites, and local migmatites and granitics

GEOLOGIC MAP OF THE NORTH

Contact
Dashed where inferred or approximately located

Gradational contact

Fault
Dashed where inferred or approximately located; dotted where concealed; U, upthrown side; D, downthrown side

Fault, showing dip

Vertical fault

Fault, showing lateral displacement

Thrust fault
T, *upper plate*

Strike and dip of beds

Strike and dip of overturned beds

Strike of vertical beds

Horizontal beds

Strike and dip of foliation

Strike of vertical foliation

Prevailing strike and dip of beds and foliation

Vertical shaft

Adit

Prospect pit

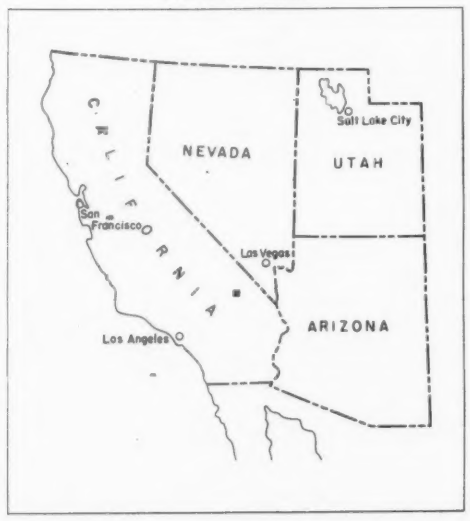
Fossil locality

Scale 1:31 680

1 1/2 0 1 Mile

Contour interval 200 feet
Datum is mean sea level

INDEX MAP



TRUE NORTH

MAGNETIC

APPROXIMATE DECLINATION,

RTHEAST PART OF THE SODA MOUNTAINS, SAN BERNARDINO COUNTY, CAL

iated. Clasts

ite, medium to
orm

, medium-

arge scale directionless
iary plutonic types

ite, medium to dark
ed groundmass

ay, fine to medium-

broic and dioritic
more acidic migmatites

undifferentiated

iated. Irregular and inter-
and light limestone

CENOZOIC

MESOZOIC

PALEOZOIC

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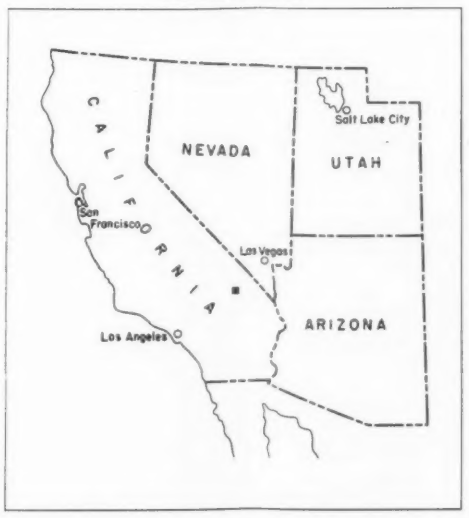
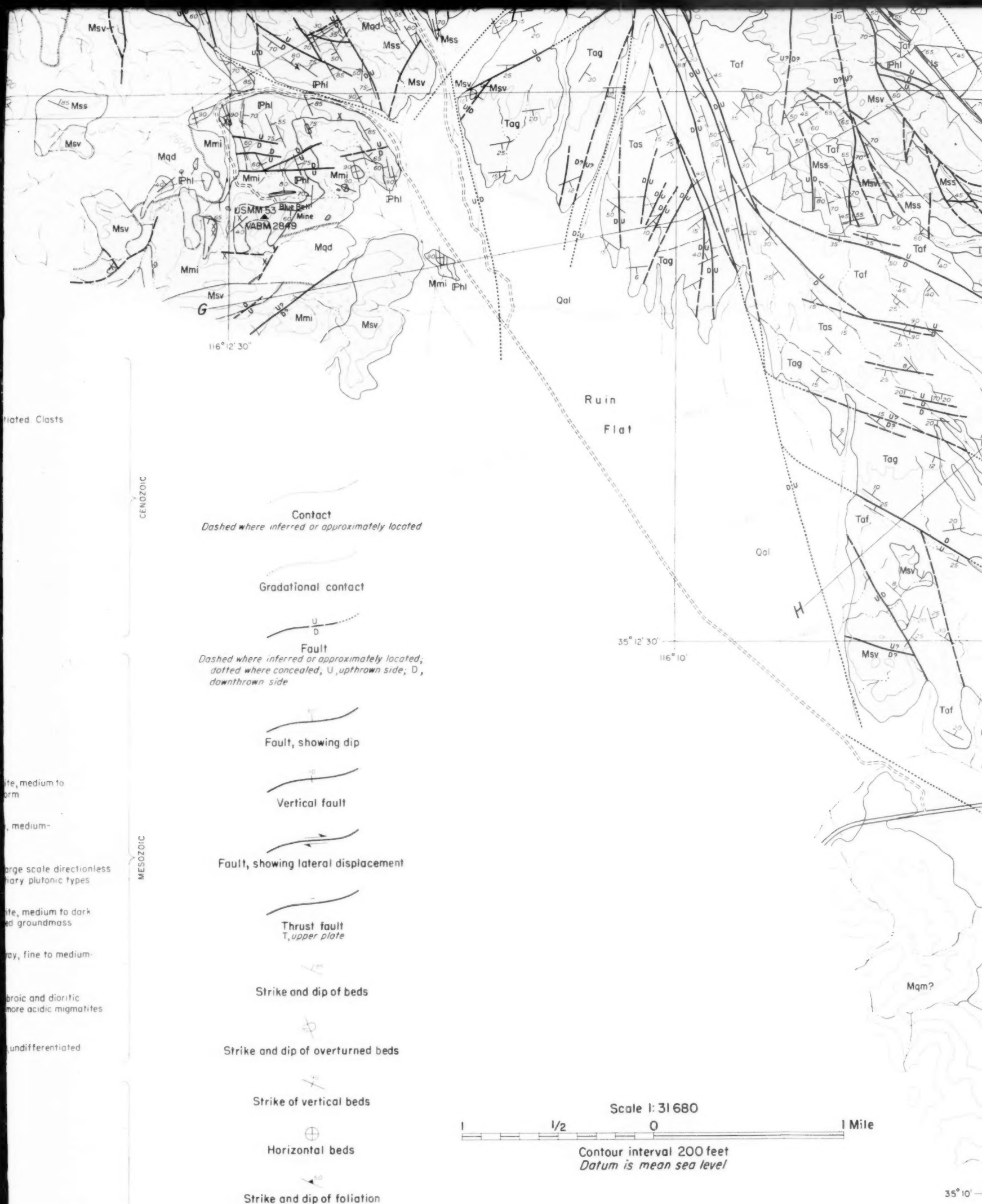


AP OF THE NORTHEAST PART OF THE SODA MOUNTAINS, SAN BERNARDINO C

COUNTY, CALIFORNIA



...iated Clasts

...ite, medium to ...orm

..., medium-

...arge scale directionless ...iary plutonic types

...ite, medium to dark ...ed groundmass

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1 1/2 0 1 Mile

Contour interval 200 feet
Datum is mean sea level

INDEX MAP

AP OF THE NORTHEAST PART OF THE SODA MOUNTAINS, SAN BERNARDINO

O COUNTY, CALIFORNIA

LEGEND

IGNEOUS ROCKS

- Alluvium
- Pillow lavas and tuffs
- *gd* — Granodiorite and diorite
- *amp* — Amphibolite
- *py* — Pyroxenite
- Nodular serpentinite
- *gn* — Fine-grained serpentinite (greenstone) with and without microscopic actinolite

SCHISTS

- *sh* — Undifferentiated carbonaceous "chloritic mica" schists
- Garnet-muscovite schist
- Black argillite
- Manganiferous schist
- Graphitic garnetiferous schist
- Epidote-quartz-mica schist

CARBONATE ROCKS

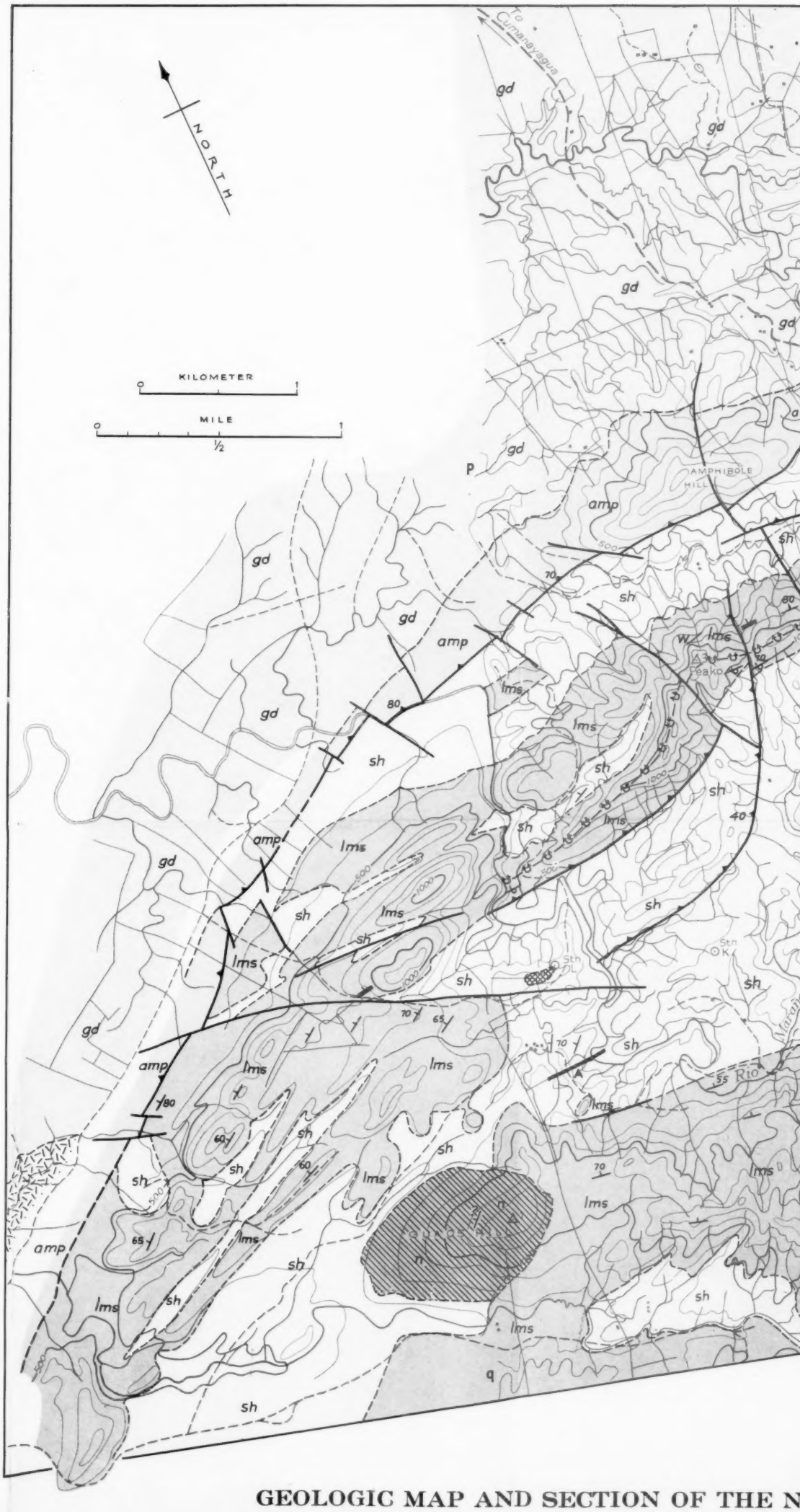
- Dolomite horizon
- *d* — Dolomite
- *lms* — Undifferentiated limestone

- Geological boundary (generally faulted and inferred)
- Strike and dip
- Strike, dip presumed overturned
- Strike, vertical dip
- Strike, dip unknown
- Fault, dip as indicated
- Fault, assumed
- Axis, overturned antiform
- Gossan
- Magnetite-chlorite schist (locality) — M
- Brucite limestone (locality) — W, X, Y, Z
- Actinolite vein — A
- Road
- Track
- Fence
- Building
- Drainage
- Triangulation point
- Important plane-table station
- Contours

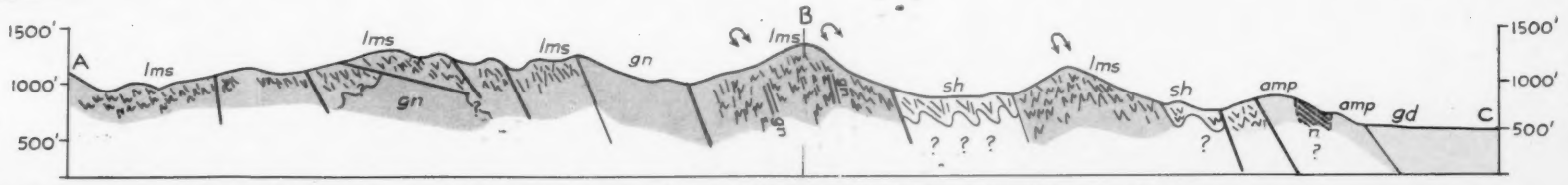
NOTES

Dip and strike symbols for bedding are centered in circular sample cells of approximately 1000 square feet area, and where angle of dip is given, represent the means of 5 to 10 replicated readings rounded off to the nearest 5°. Dip figures for faults, with the exception of the amphibolite contact, were obtained photogrammetrically.

Geology by Hill 1951, 1952-1953. Area between triangulation points plane-tabled by Hill and Lewko 1952-1953. Photogrammetric extension 1954-1955. Precision deteriorates westward, especially west of P-Q. Topographic names in English are provisional only. Revised and corrected 1959.



GEOLOGIC MAP AND SECTION OF THE N



E NORTHWEST TRINIDAD MOUNTAINS, LAS VILLAS PROVINCE, CUBA

LEGEND

IGNEOUS ROCKS

- Alluvium
- Pillow lavas and tuffs
- gd — Granodiorite and diorite
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- Strike, vertical dip
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- Gossan
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- Brucite limestone (locality)
- Actinolite vein
- Road
- Track
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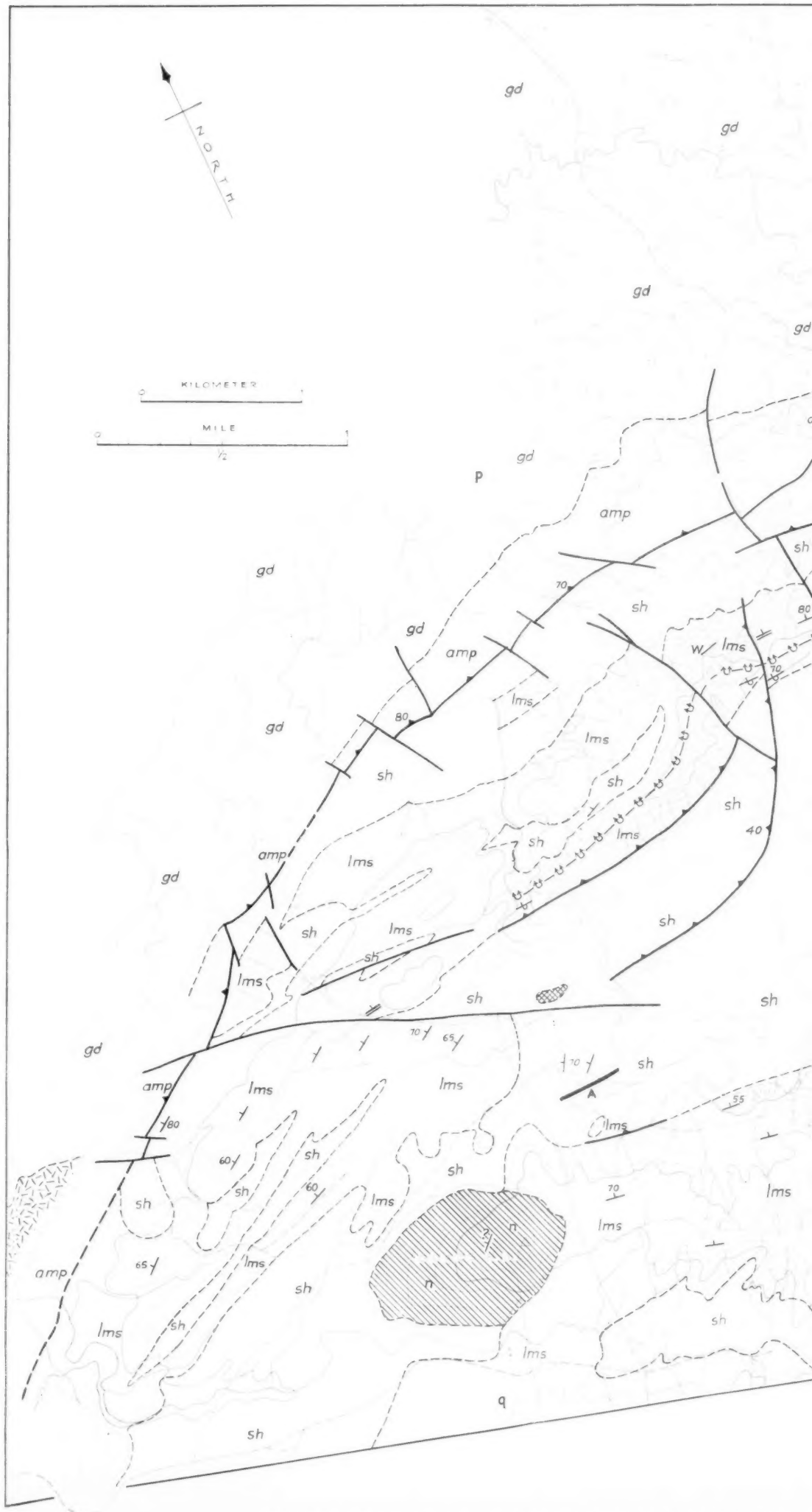
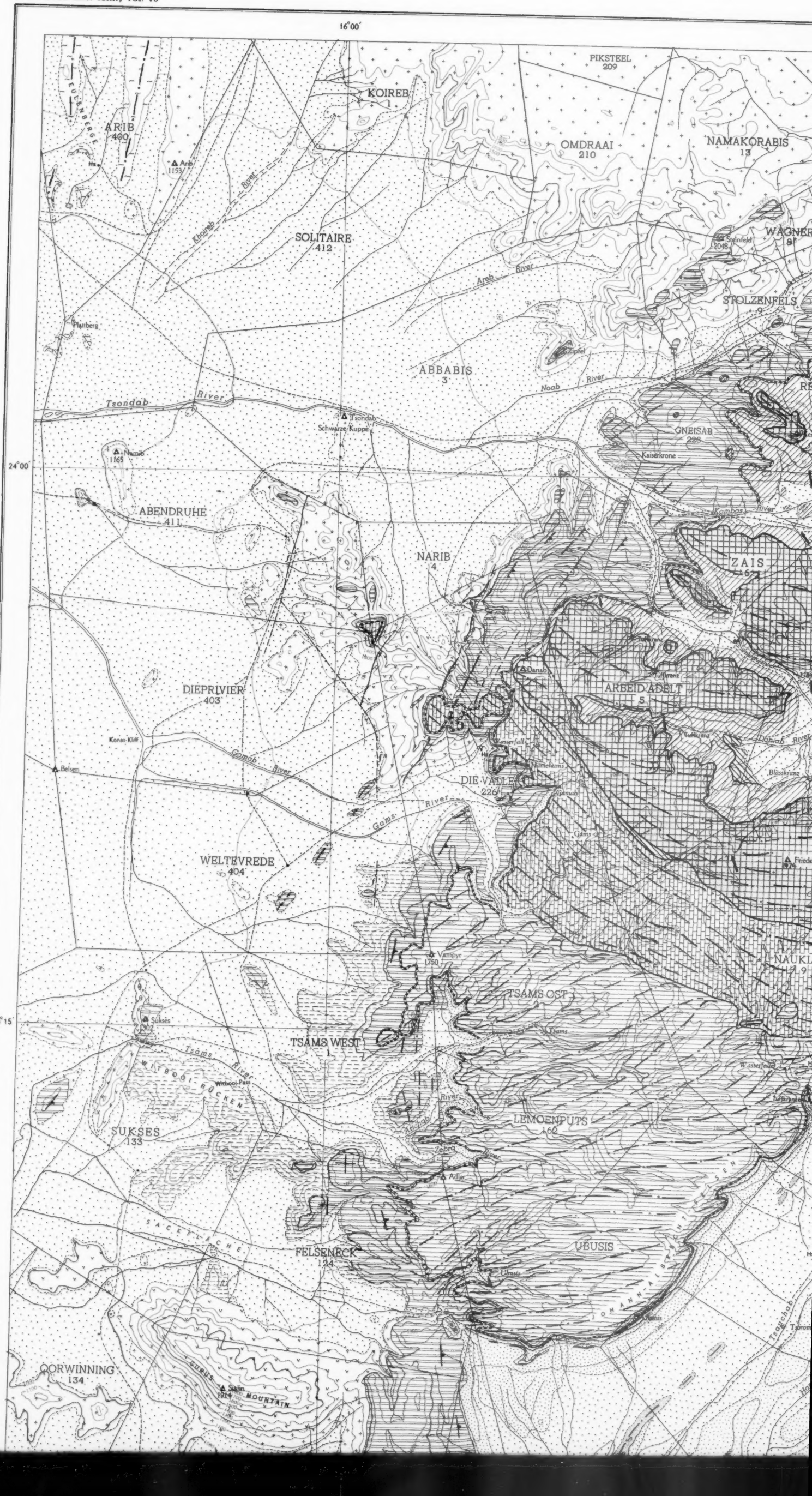


GEOLOGIC MAP AND SECTION OF THE N

E NORTHWEST TRINIDAD MOUNTAINS, LAS VILLAS PROVINCE, CUBA

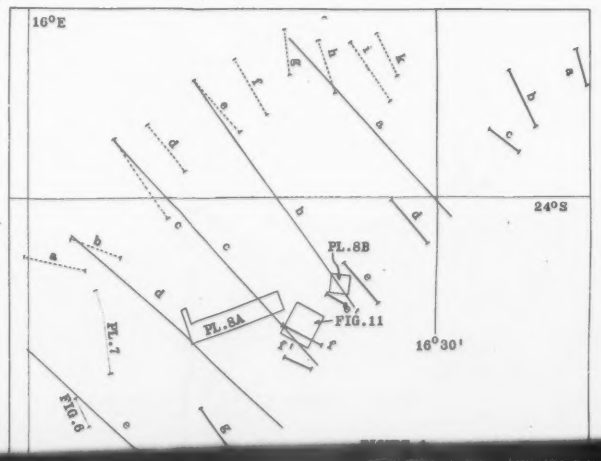

16°00'
24°00'
24°15'
PIKSTEEL
209
KOIREB
1
ARIB
400
EUGENBERGE
Hs
Anib
1153
OMDRAAI
210
NAMAKORABIS
13
Khoreb River
SOLITAIRE
412
Steinfeld
2048
WAGNER
8
Areb River
STOLZENFELS
9
Plattberg
Zipfel
ABBABIS
3
Noab River
Tsondab River
Tsondab
Schwarze Kuppe
GNEISAB
228
Kaiserkrone
Namib
1165
ABENDRUHE
411
Kambas River
NARIB
4
ZAIS
6
Danab
Tafelkranz
ARBEID ADELT
5
DIEPRIVIER
403
Konas-Kliff
Gamab River
Belsen
Wasserfall
Hamchams
DIE VALLEI
226
Gams River
WELTEVREDE
404
Vampyr
1750
TSAMS OST
Sukses
1302
TSAMS WEST
Tsams River
WITBOOI-RÜCKEN
Witbooi-Pass
Tsams
Wasserfaule
Tafelkranz
Aruchab River
LEMOENPUTS
162
SUKSES
133
Zebra River
Adler
SACKFLÄCHE
FELSENECK
124
UBUSIS
Ubusis
JOHANN-ALBRECHT-HÖHEN
Tsaobchab
OORWINNING
134
GURUS MOUNTAIN
Satin
1914

16°15′ 16°30′

GUISIS 180
KABIRAS 343
AUCHAS 347
NUWEDAM 348
KLEIN AUB 350
DIAMANT 349
LEPEL 339
NAUZERUS 11
NAUZERUS WEST 229
NOAB 10
REMHOOGTE 227
BLÄSSKRANZ 7
BÜLLSPORT 172
NAUKLUFT 9
NEU ONIS 10
ONIS 8

Lepel
Nauzerus
Slangpoort 1723
Garis
Garis 1720
Rooiwal
Blesskranz
Friedensberg 1974
Triumpf
Onis 1707
Onis Qu.
Slangkolk

Tsondab River
Tsondab River
Tsondab River
Kodhub River
Angonia River
Gabis River
Tsaromas River
Hanichas River
Bastard Werft
BÜLLSPORT PLAIN



LEGEND

- Surface deposits
- Dwyka tillite, Karroo System
- Klipbok Series
- Kudu Series
- Dassie Series
- Pavian Series, northern facies
- Pavian Series, southern facies
- Zebra Series
- Dolomite
- Unconformity
- Schwarzrand Series
- Schwarzkalk Series
- Tsumis System
- Damara System
- Sinclair Series

16°15′

PIKSTEEL 209

GUISIS 180

KABIRAS 343

OMDRAAI 210

NAMAKORABIS 13

NAUZERUS WEST 229

NAUZERUS 11

WAGNER 8

Steinfeld 2048

NOAB 10

STOLZENFELS 9

Grenzberg

Zipfel

Noab River

REMHOOGTE 227

GNEISAB 228

Kaiserkrone

Kambas River

ZAIS 6

Roonwal

Quibis

Tsubgams

KUDU PLATEAU

Danab

Tuffkranz

ARBEID ADELT 5

BLÄSSKRANZ 7

Tsondab River

Toms

Wasserfall

Hamelstims

Gamab

Blässkranz

Bleskranz

Gams

Friedensberg

Aub

BÜLLSPORT 172

BÜLLSPORT PLAIN

Bastard Werft

Triumpf

NAUKLUFT 9

TSAMS OST 2

Tsams

Wasserfall

Hs

LEMOENPUTS 162

NEU ONIS 10

Onis 1707

Kochab River

Anghois River

UBUSIS

Ubusis

JOHANNA-ALBRECHTSHÖHE

Onis Qu.

ONIS 8

Tsaobchab River

Tsaromas

Hanichas River

16°E

Fl. 8A

Fl. 7

16°30′ 16°45′

AUCHAS 347

NUWEDAM 348

KLEIN AUB 350

CAMBELLS AUB

DIAMANT 349

LEPEL 339

Lepel

Slangpoort 1723

Slangpoort

Garis

Roaskeur

Garis 1720

Achaub 1583

Achaub

24°00′

Gabis

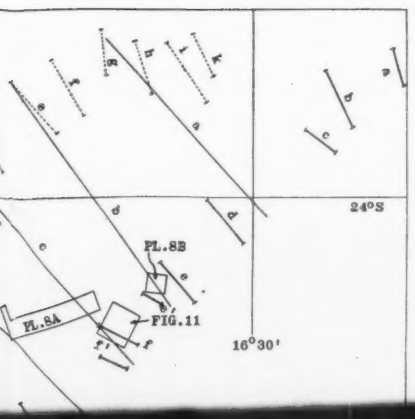
Gabis

S T A R D — L A N D

Slangkolk

Swart

24°15′



LEGEND

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- *Dwyka tillite, Karroo System*
- *Klipbok Series*
- *Kudu Series*
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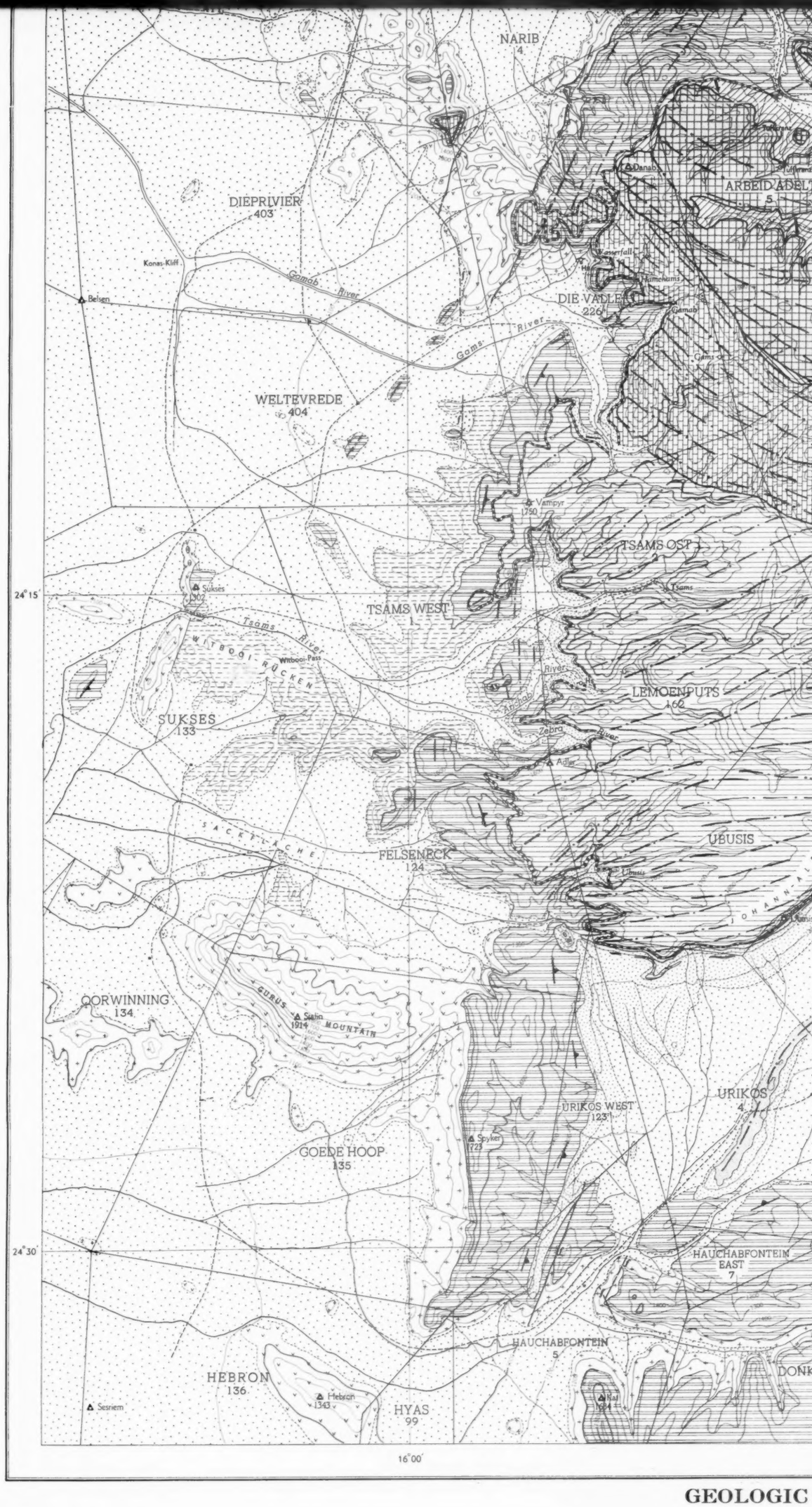
- *Pavian Series, northern facies*
- *Pavian Series, southern facies*
- *Zebra Series*
- *Dolomite*
- *Unconformity*
- *Schwarzrand Series*
- *Schwarzkalk Series*

Nama System

- *Tsumis System*
- *Damara System*


NARIB
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Tsams River
Witbooi-Pass
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162
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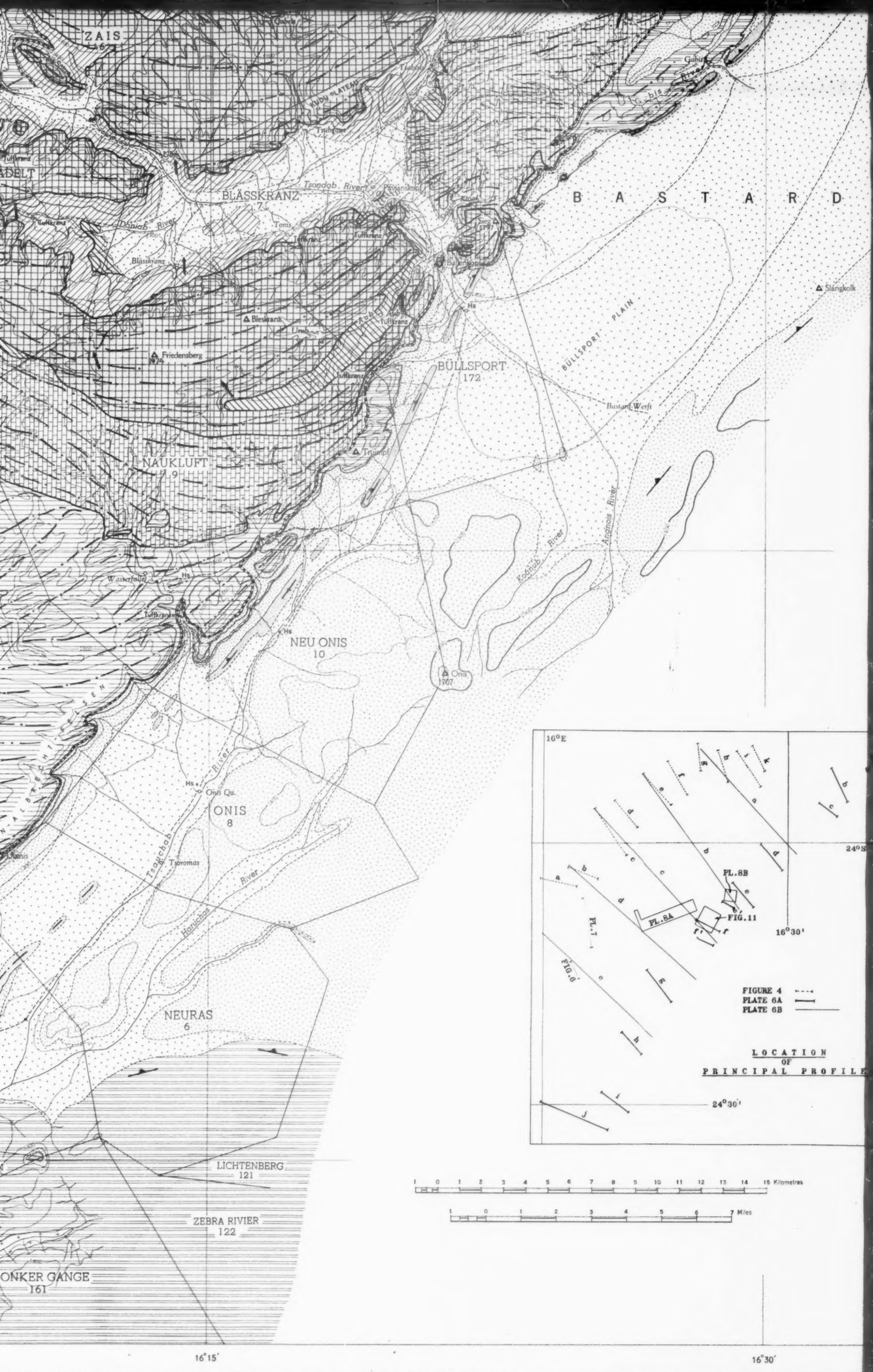
SACKFLÄCHE
FELSENECK
124
JOHANNA
OORWINNING
134
GURUS
Sisha
1914
MOUNTAIN
GOEDE HOOP
135
URIKOS WEST
123
Spyker
1723
URIKOS
4
HAUCHABFONTEIN EAST
7
HAUCHABFONTEIN
5
DONK
HEBRON
136
Hebron
1343
Sesriem
HYAS
99
Nul
1914
24°15'
24°30'
16°00'

GEOLOGIC



IC MAP OF THE NAUKLUFT MOUNTAINS AREA, SOUTH WEST AFRICA

GEOLOGIC MAP OF THE NAUKLUFT MOUNTAINS AREA, SOUTH

7 8 9 10 11 12 13 14 15 Kilometres

5 4 5 6 7 Miles

LEGEND

- Surface deposits
- Dwyka tillite, Karroo System
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  - Klipbok Series
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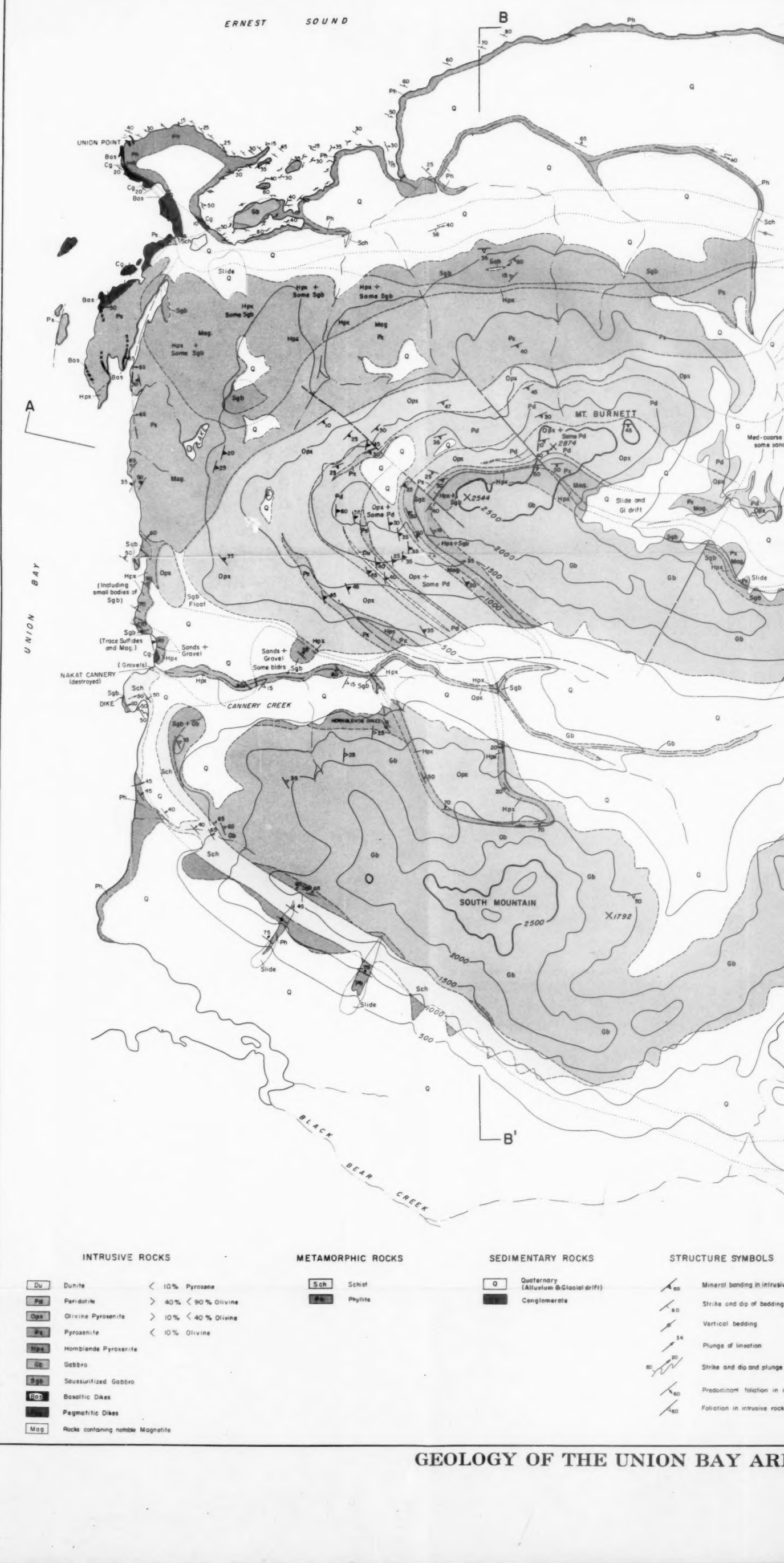
  - Dolomite
  - Unconformity
  - Schwarzrand Series
  - Schwarzkalk Series
- Tsumis System
- Damara System
- Sinclair Series
- Granite, gneiss, amphibolite & migmatite
- Fault, visible
- Fault, not visible
- Lineation
- Strike and dip
- Direction of folding axes
- Water-hole
- Permanent spring or well
- Trigonometrical beacon with height shown in metres
- Contours at 100 metres vertical intervals
- Road
- House

TH WEST AFRICA

Drawn in the Geological Survey Office, Pretoria, 1957.



INTRUSIVE ROCKS

Du	Dunite	< 10% Pyroxene
Pd	Peridotite	> 40% < 90% Olivine
Opx	Olivine Pyroxenite	> 10% < 40% Olivine
Px	Pyroxenite	< 10% Olivine
Hpx	Hornblende Pyroxenite	
Gb	Gabbro	
Sgb	Saussuritized Gabbro	
Bas	Basaltic Dikes	
	Pegmatitic Dikes	
Mag	Rocks containing notable Magnetite	

METAMORPHIC ROCKS

Sch	Schist
Ph	Phyllite

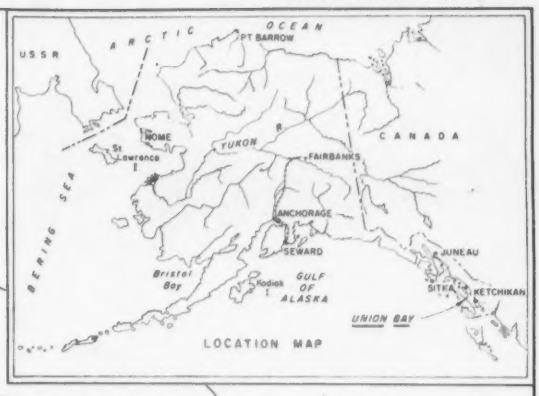
SEDIMENTARY ROCKS

Q	Quaternary (Alluvium & Glacial drift)
	Conglomerate

STRUCTURE SYMBOLS

- Mineral banding in intrusiv
- Strike and dip of bedding
- Vertical bedding
- Plunge of lineation
- Strike and dip and plunge
- Predominant foliation in
- Foliation in intrusive rock

GEOLOGY OF THE UNION BAY AR



VIXEN INLET

VIXEN CREEK

LAKE

LAKE

LAKE

Sands and Coarse Boulders

Gl till

Slide

Slide + Gl debris

Gb Some Sgb

Gl drift

Bedded (flat) Gl till

All Du boulders in float

2000

1500

1000

500

2500

2535

2310

A

A'

C

C'

Q Px Fl(coarse)

d-coarse gravel; ome sand

CONTACTS

- Well exposed
- Poorly exposed; approximately located
- Covered
- Dip of contacts

plunge of folds

on in metamorphic rocks

ve rocks

GEOLOGY BY JOHN C. RUCKMICK

1954 – 1956

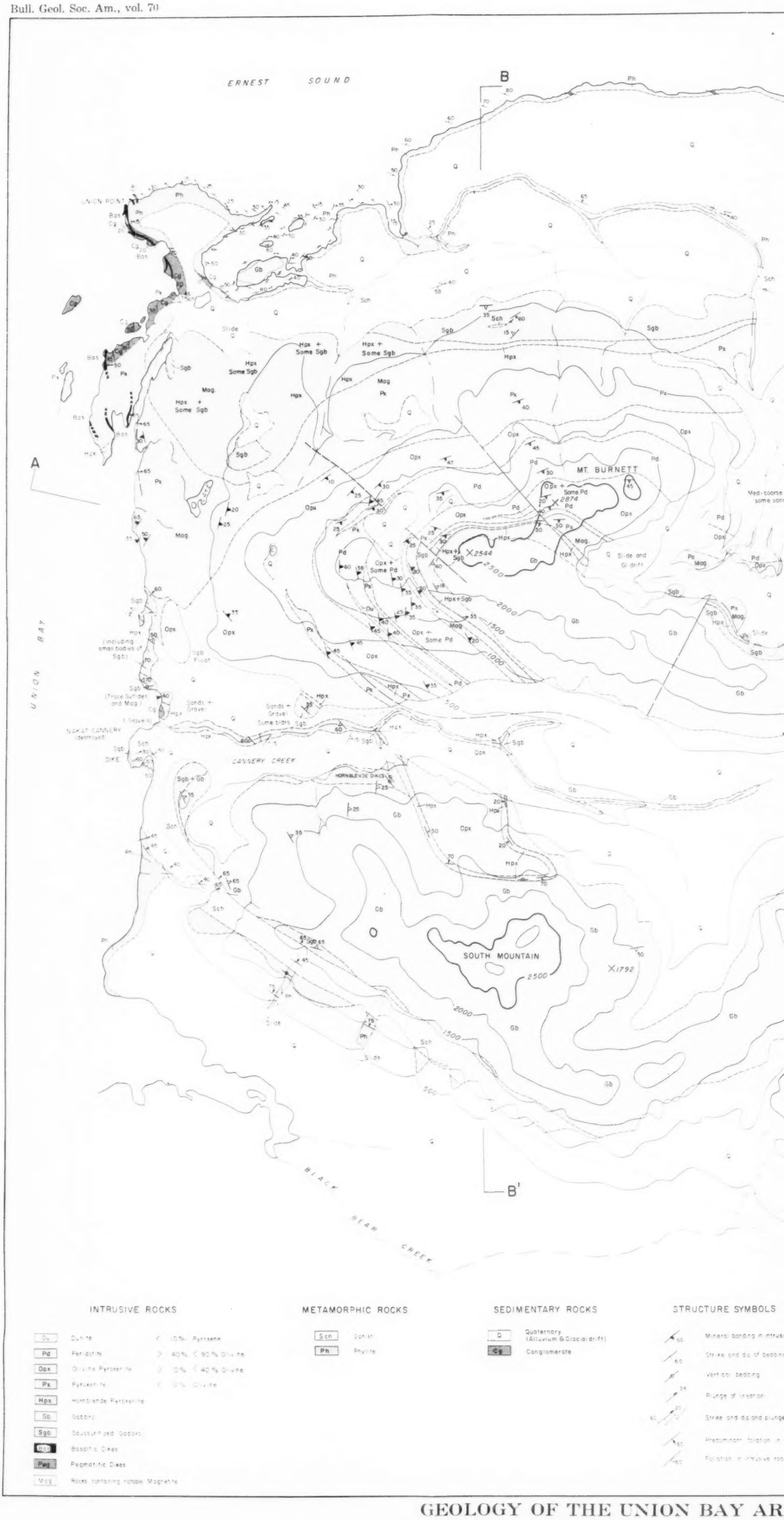
N

SCALE IN FEET

1320 660 0 1320 2640 3960 5280 6600

CONTOUR INTERVAL 500 FEET

AREA, SOUTHEASTERN ALASKA



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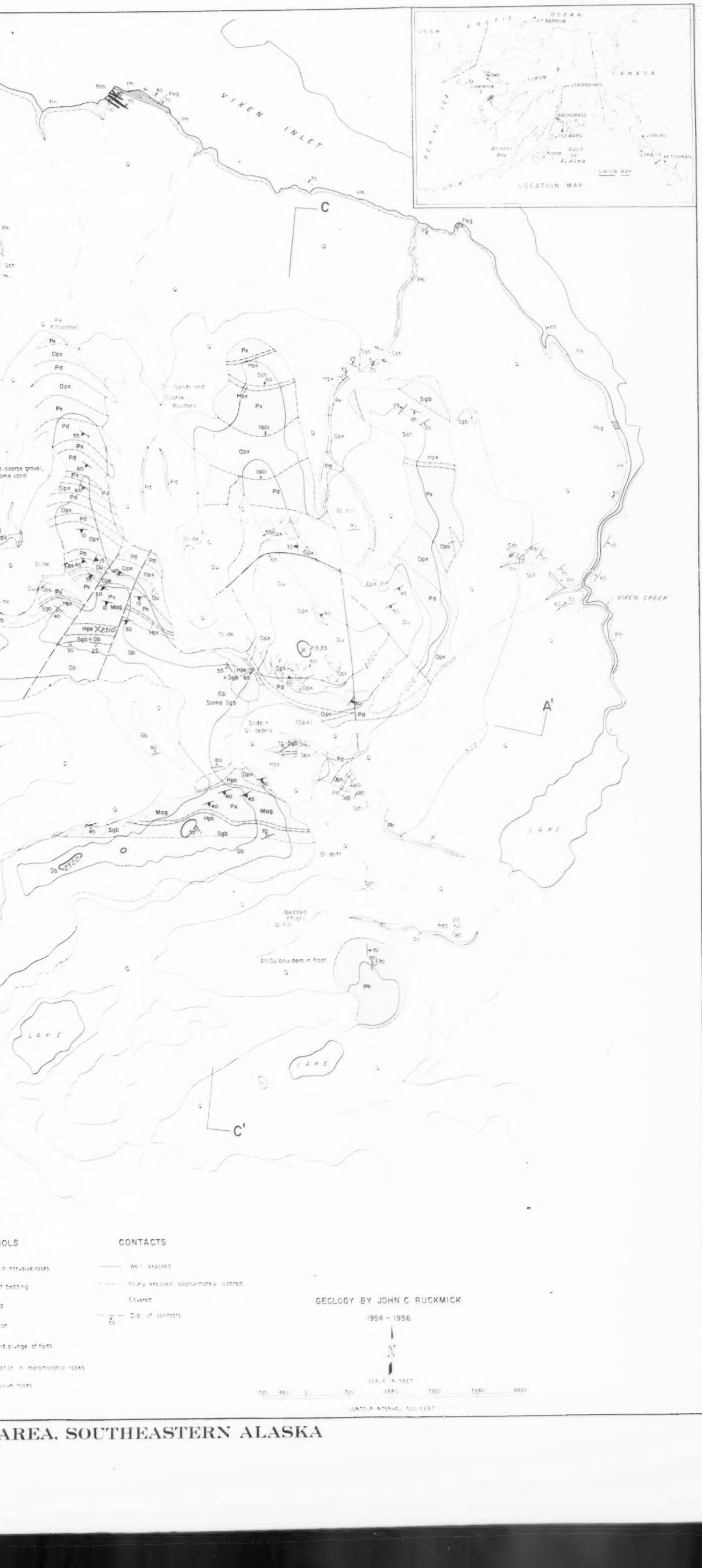
STRUCTURE SYMBOLS

- Mineral banding in intrusi
- Strike and dip of bedding
- Vertical bedding
- Plunge of lineation
- Strike and dip and plunge
- Presumed fracture in
- Foliation in intrusive roc



OLS

CONTACTS

- n intrusive rocks
- f bedding
- g
- or
- nd plunge of folds
- ation in metamorphic rocks
- sive rocks

Accurately exposed

Poorly exposed, approximately located

Covered

Dip of contacts

GEOLOGY BY JOHN C. RUCKMICK

1954 – 1956

SCALE IN FEET

0 320 640 1320 2640 3960 5280 6600

CONTOUR INTERVAL 500 FEET

AREA, SOUTHEASTERN ALASKA

ACTINIUM	Ac	89
Actinium A (AcA) - Po^{215}		
Actinium B (AcB) - Pb^{211}		
Actinium C (AcC) - Bi^{211}		
Actinium C' (AcC') - Po^{211} (metastable)		
Actinium C'' (AcC'') - Tl^{207}		
Actinium D (AcD) - Pb^{207}		
Actinium K (AcK) - Fr^{223}		
Actinium X (AcX) - Ra^{223}		
Actinon (An) - Rn^{219}		
Actinouranium (AcU) - U^{235}		
Alabamine - astatine		
Aldebaranium - ytterbium		
Aluminium - aluminum		
ALUMINUM	Al	13
AMERICIUM	Am	95
ANTIMONY	Sb	51
Argentum - Silver		
ARGON	Ar	18
ARSENIC	As	33
ASTATINE	At	85
Aurum - gold		
Austrium - impure gallium		
BARIUM	Ba	56
BERKELIUM	Bk	97
BERYLLIUM	Be	4
BISMUTH	Bi	83
BORON	B	5
Brevium - Pa^{234}		
BROMINE	Br	35
CADMIUM	Cd	48
CALCIUM	Ca	20
CALIFORNIUM	Cf	98
CARBON	C	6
Casseopeum (Cp) - lutetium		
Celtium - lutetium		
CERIUM	Ce	58
CESIUM	Cs	55
CHLORINE	Cl	17
CHROMIUM	Cr	24
COBALT	Co	27
Columbium - niobium		
COPPER	Cu	29
Coronium - hypothetical solar element		
CURIUM	Cm	96
Cyclonium - promethium		
Demonium - dysprosium		
Deuterium (D) - H^2		
Didymium - neodymium and praseodymium		
Dvitellurium - polonium		
Dwi-manganese - rhenium		
DYSPROSIUM	Dy	66
EINSTEINIUM	Es	99
Eka-aluminum - gallium		
Eka-boron - scandium		
Eka-cesium - francium		
Eka-iodine - astatine		
Eka-manganese - technetium		
Eka-silicon - germanium		
Eka-tantalum - protactinium		
Emanation (Em) radon		
ERBIUM	Er	68
Erythronium - vanadium		
EUROPIUM	Eu	63
Ferrum - iron		
Florentium - promethium		
FERMIUM	Fm	100
FLUORINE	F	9
FRANCIUM	Fr	87
GADOLINIUM	Gd	64
GALLIUM	Ga	31
GERMANIUM	Ge	32
Glucin(i)um - beryllium		
GOLD	Au	79
HAFNIUM	Hf	72
HELIUM	He	2
HOLMIUM	Ho	67
Hydrargyrum - mercury		
HYDROGEN	H	1
Illinium - promethium		
INDIUM	In	49
IODINE	I	53
Ionium (Io) - Th^{230}		
IRIDIUM	Ir	77
IRON	Fe	26
Jod (J) - iodine		
Kalium - potassium		
KRYPTON	Kr	36
LANTHANUM	La	57
LEAD	Pb	82
LITHIUM	Li	3
Lutecium - lutetium		
LUTETIUM	Lu	71
MAGNESIUM	Mg	12
MANGANESE	Mn	25
Masurium - technetium		
MENDELEVIUM	Md	101
MERCURY	Hg	80
Mesothorium$_1$ ($MsTh_1$) - Ra^{228}		
Mesothorium$_2$ ($MsTh_2$) - Ac^{228}		
MOLYBDENUM	Mo	42
Natrium - sodium		
Nebulium - hypothetical cosmic element		
NEODYMIUM	Nd	60
Neoytterbium - ytterbium		
NEPTUNIUM	Np	93
NEON	Ne	10
NICKEL	Ni	28
NIOBIUM	Nb	41
Nipponium (obsolete) - Re + Mo oxides (?)		
Niton - radon		
NITROGEN	N	7
NOBELIUM	No	102
OSMIUM	Os	76
OXYGEN	O	8
PALLADIUM	Pd	46
PHOSPHORUS	P	15
PLATINUM	Pt	78
Plumbum - lead		
PLUTONIUM	Pu	94
POLONIUM	Po	84
POTASSIUM	K	19
PRASEODYMIUM	Pr	59
PROMETHIUM	Pm	61
PROTACTINIUM	Pa	91
Radioactinium (RdAc) - Th^{227}		
Radiothorium (RdTh) - Th^{228}		
RADIUM	Ra	88
Radium A (RaA) - Po^{218}		
Radium B (RaB) - Pb^{214}		
Radium C (RaC) - Bi^{214}		
Radium C' (RaC') - Po^{214}		
Radium C'' (RaC'') - Tl^{210}		
Radium D (RaD) - Pb^{210}		
Radium E (RaE) - Bi^{210}		
Radium E'' (RaE'') - Tl^{206}		
Radium emanation - radon		
Radium F (RaF) - Po^{210}		
Radium G (RaG) - Pb^{206}		
RADON	Rn	86
RHENIUM	Re	75
RHODIUM	Rh	45
RUBIDIUM	Rb	37
RUTHENIUM	Ru	44
SAMARIUM	Sm	62
SCANDIUM	Sc	21
SELENIUM	Se	34
SILICON	Si	14
SILVER	Ag	47
SODIUM	Na	11
Stannum - tin		
Stibium - antimony		
STRONTIUM	Sr	38
SULFUR	S	16
TANTALUM	Ta	73
TECHNETIUM	Tc	43
TELLURIUM	Te	52
TERBIUM	Tb	65
THALLIUM	Tl	81
THORIUM	Th	90
Thorium A (ThA) - Po^{216}		
Thorium B (ThB) - Pb^{212}		
Thorium C (ThC) - Bi^{212}		
Thorium C' (ThC') - Po^{212}		
Thorium C'' (ThC'') - Tl^{208}		
Thorium D (ThD) - Pb^{208}		
Thorium X (ThX) - Ra^{224}		
Thoron (Tn) - Rn^{220}		
THULIUM	Tm	69
TIN	Sn	50
TITANIUM	Ti	22
Tritium (T) - H^3		
TUNGSTEN	W	74
URANIUM	U	92
Uranium (I) - U (I) - U^{238}		
Uranium (II) - U (II) - U^{234}		
Uranium X_1 (UX_1) - Th^{234}		
Uranium X_2 (UX_2) - Pa^{234} metastable		
Uranium Y (UY) - Th^{231}		
Uranium Z (UZ) - Pa^{234}		
VANADIUM	V	23
Virginium - francium		
Wolfram - tungsten		
Wolframium - tungsten		
XENON	Xe	54
YTTERBIUM	Yb	70
YTTRIUM	Y	39
ZINC	Zn	30
ZIRCONIUM	Zr	40

élément
Element
elemento
элемент

poids atomique
Atomgewicht
peso atómico
атомный вес

le poids d'un atome × 10^{-24} grammes
Gewicht eines Atoms × 10^{-24} Gramm
el peso de un átomo × 10^{-24} gramos
вес одного атома × 10^{-24} граммов

abondances
Gehalte
abundancias
относительное содержание

moyenne
arithmétique
Arithmetischer
Durchschnitt
promedio aritmético
среднее
арифметическое

A

b numéro de analyses
Anzahl der Analysen
número de análisis
количество анализов

c déviation normale
Normale Streuung
desviación normal
нормальное отклонение

▲ extrusif
extrusiv
extrusivo
эффузивные породы

● intrusif

hydrolysate pélagique Meerhydrolysat hidrolizato pelágico глубоководные осадки	océan Ozean océano океан	sulfite météoritique Meteorsulfid sulfito meteorítico метеорный сульфид
argile schisteuse Schieferton lutita глинистый сланец	roches métamorphiques Metamorphes Gestein rocas metamórficas метаморфические породы	fer météoritique Meteoreisen hierro meteorítico метеорное железо
grès Sandstein arenisca песчаник	autre Andere otro другие	silicate météoritique Meteorsilikat silicato meteorítico метеорный силикат

Group → / Series ↓	1 — R_2O	2 — RO	3 — R_2O_3	RH_4
1	**H** 1.0080 (1.6733)			
2	**Li** 6.940 (11.52)	**Be** 9.013 (14.96)	**B** 10.82 (17.96)	**C** 12.011 (19.937)
3	**Na** 22.991 (38.165)	**Mg** 24.32 (40.37)	**Al** 26.98 (44.79)	**Si** 28.09 (46.63)
4	**K** 39.100 (64.907)	**Ca** 40.08 (66.534)	**Sc** 44.96 (74.634)	**Ti** 47.90 (79.515)
5	**Cu** 63.54 (105.5)	**Zn** 65.38 (108.5)	**Ga** 69.72 (115.7)	**Ge** 72.6 (120.5
6	**Rb** 85.48 (141.9)	**Sr** 87.63 (145.4)	**Y** 88.92 (147.6)	**Zr** 91.22 (151.4)
7	**Ag** 107.880 (179.083)	**Cd** 112.41 (186.60)	**In** 114.82 (190.60)	**Sn** 118.7 (197.0
	Cs 132.91 (220.63)	**Ba** 137.36 (228.02)	**La** 138.92 (230.61)	**Ce** 140.13 (232.62)

RO–	3 R_2O_3	4 RO_2	RH_3	5 R_2O_5	RH_2

B — 10.82 (17.96) — 5

0	(96)	12	3.71					
+3	.21	3	.039	.15	1715	37.75	B+3 (49)	0.89
+3	.22	4	.045	.16			B+3 (.64)	

1s2-2s2-2p1

$ 0.21–0.23/gm

COLEMANITE 15.7 SUSSEXITE 10.0
SASSOLITE 17.5 DATOLITE 6.8
ULEXITE 13.3 TOURMALINE
BORAX 11.4 AXINITE

97.2 ▲ 86.7 ▲ -63.55 ▲ 36.65 ▲ 1.56

C — 12.011 (19.937) — 6

0	.66	1	1.20					
0	.71	3	1.50					
0	.77	4	1.91					
0	(.87)	12	2.76					
+4	.15	3	.014	.11	3520	64.19	C+4 (.044)	
							C+4 (.059)	

1s2-2s2-2p2

$ 0.21–0.36/kg

DIAMOND 100 DOLOMITE 13.0
GRAPHITE 100 CALCITE 11.8
AMBER 38 STRONTIANITE 8.4
WHEWELLITE 16.6 CARBONATE-APATITE 12

171.70 ▲ 180.85 ▲ -117.897 ▲ 37.76 ▲ 1.36

N — 14.008 (23.254) — 7

0	.56	1	.74					
–3								
+3	.15	3	.014	.11	980	47.17	N 0.70	
+5	.12	5	.0072	.09	5800	97.43	N (0.60)	

1s2-2s2-2p3

$ 1.50–8.90/L

SALAMMONIAC 26.2 NITROCALCITE 10.9
OXAMMITE 17.0 SIDERAZOT 9.1
SODA-NITER 16.5 GERHAROTITE 5.9
NITER 13.9 DARAPSKITE 5.8

(N_2) 45.77 ▲ 1.9

O — 16 (26.560) — 8

0	.66	1	1.20					
–2	1.40		11.49					
+6	.10		.0042					

1s2-2s

$ 1.50–8.50/L

QUARTZ 53.1 ENSTA
ALBITE 48.8 HEMAT
CALCITE 48.0 ARSEN
CORUNDUM 47.1 CUPRIT

(O_2) 49.0

Al — 26.98 (44.79) — 13

0	1.39	8	11.3					
0	1.43	12	12.3					
+3	.49	4	.49	.35	1280	28.31	Al+3 0.68	
+3	.51	6	.56	.36			Al+3 0.85	

3s2-3p1

$ 0.52–1.51/kg

CORUNDUM 52.6 MUSCOVITE ± 20
GIBBSITE 33.9 KAOLINITE 19
KYANITE 33.3 CRYOLITE 13.0
TOPAZ 29.3 ORTHOCLASE 9.7

75.00 ▲ 65.3 ▲ -47.86 ▲ 39.30 ▲ 6.77

Si — 28.09 (46.63) — 14

0	1.17	4	6.71					
0	1.26	8	8.38					
0	1.30	12	9.20					
–4	1.98		32.5					
+4	.40	4	.27	.29	2500	44.95	Si+4 (.65)	
							Si+4 0.80	

3s2-3p2

$ 1.98–6.00/kg

QUARTZ 46.8 ANORTHITE 20.0
TALC 29.7 ANDALUSITE 17.2
MUSCOVITE 21.1 ALMANDITE 18.9
ANTIGORITE 20.8 FAYALITE 13.8

88.04 ▲ 77.41 ▲ -56.740 ▲ 40.12 ▲ 4.47

P — 30.975 (51.419) — 15

0	.94	1	3.48					
0	1.09	3	5.42					
–3								
+3	.42	4	.31	.30	790	30.0	P 1.10	
+5	.33	4	.15	.24	4000	64.74	P+3 (.74)	
							P+3 (.89)	

3s2-3p3

$ 0.83–2.97/kg

AMBLYGONITE 20.0 MONAZITE 12.0
LAZULITE 19.8 AUTUNITE 6.3
APATITES 17.2 in DESSARTITE 1.8
SCHREIBERSITE 14.6

75.15 ▲ 66.71 ▲ -48.897 ▲ 38.98 ▲ 10.6

S — 32.066 (53.230) — 16

0	.96	1	3.71					
0	1.06	2	4.99					
–2	1.85		26.5					
+4	.35	4	.18	.25	275			
+6	.29	4	.10	.21	6000			

3s2-

$ 5.94–22.50/kg

DAUBREELITE 35.9 DIETZEIT
CHROMITES 34.6 FUCHSITE
UVAROVITE 20.9 in DIOPSI
CROCOITE 16.1 in FORSTERITE

80.5 ▲ 69.8 ▲ -51.16 ▲ 41.6

Sc — 44.96 (74.634) — 21

0	1.59	8	16.8					
0	1.64	12	18.5					
+3	.81	6	2.23	.58	1075	24.64	Sc+3 0.96	
							Sc+3 1.09	

3d1-4s2

OXIDE $ 20.00–60.00/gm

THORTVEITITE ± 27.1 in CASSITERITE .65
in BERYL in WOLFRAMITE
in WIIKITE .65 in FERROMAGNESIAN MINERALS

93 ▲ 41.76 ▲ 23

Ti — 47.90 (79.515) — 22

0	1.41	8	11.7					
0	1.45	12	12.8					
+3	.76	6	1.84	.54	1160	27.6	Ti+3 1.03	
+4	.68	6	1.32	.49	2150	44.66	Ti+4 1.06	

3d2-4s2

$ 24.20–26.40/kg

RUTILE 43.2 SPHENE 24.5
ILMENITE 31.9 BETAFITE 12.7
PEROVSKITE 30.4 in LEPIDOMELANE 2.7
SCHORLOMITE in HORNBLENDE .8

95 ▲ 84 ▲ -61.6 ▲ 43.07 ▲ 7.24

V — 50.95 (84.58) — 23

0	1.36	12	10.5					
+2	.88	6	2.85	.63		14.7		
+3	.74	6	1.70	.53	1115	29.6	V+3 1.03	
+4	.63	6	1.05	.45	2180	48.3	V+4 1.02	
+5	.56	4	.74	.40	3600	68.64	V+5 1.07	
+6	.59	6	.86	.42				

3d3-4s2

$ 19.00–22.50/kg

PATRONITE 28 COULSONITE 4.8
SULVANITE 13.9 ROSCOELITE ± 2
CARNOTITE 11.8 in ASPHALT
VANADINITE 10.0 in APATITE

120 ▲ 109 ▲ -79.90 ▲ 43.55 ▲ 7.05

Cr — 52.01 (86.34) — 24

0	1.24	8	7.99					
0	1.28	12	8.78					
+3	.63	6	1.05	.45	1140			
+6	.49	4	.49	.35	6200			

3d5-

$ 5.94–22.50/kg

DAUBREELITE 35.9 DIETZEIT
CHROMITES 34.6 FUCHSITE
UVAROVITE 20.9 in DIOPSI
CROCOITE 16.1 in FORSTERITE

80.5 ▲ 69.8 ▲ -51.16 ▲ 41.6

Ga — 69.72 (115.7) — 31

0	1.34	8	10.1					
0	1.37	12	10.8					
+3	.59	4	.86	.42	1300	30.58	Ga+3 .91	
+3	.62	6	1.00	.44				

4p1

$ 5.00–7.50/gm

in DIASPORE 1500 ppm in ALBITE 75 ppm
in MUSCOVITE 220 ppm in SPHALERITE
in SILLIMANITE 100' ppm Temp. <10 ppm
in GERMANITE 1.85% <100 ppm
100-1000 ppm

66.0 ▲ 57.0 ▲ -41.78 ▲ 40.38 ▲ 10.2

Ge — 72.60 (120.5) — 32

0	1.22	4	7.61					
0	1.35	8	10.3					
0	1.39	12	11.3					
+2	.73	6	1.63	.52		15.86	Ge+4 .88	
+4	.50	4	.52	.36	2320	45.50		

4p2

$ 0.38–1.95/gm

in LEPIDOLITE 100' ppm ARGYRODITE 5.5
in STANNITE 100 ppm in SPHALERITE 0.036
in ENARGITE (200-600 ppm)

78.44 ▲ 69.50 ▲ -50.943 ▲ 40.11 ▲ 10.14

As — 74.91 (124.3) — 33

0	1.45	12	12.8					
0	1.22	3	7.61					
–3								
+3	.55	4	.70	.39	750	28.19	As 1.18	
+3	.58	6	.82	.41	1265		As+3 .63	
+5	.44	4	.36	.31	3735	62.4	As+3 0.05	
							As+5 1.90	

4p3

$ 1.05–1.22/kg

NATIVE As 98.1 ARSENOPYRITE 44.8
SMALTITE 69.4 COBALTITE 44.1
ORPIMENT 60.9 ERYTHRITE 28.6
NICCOLITE 53.0 PROUSTITE 14.6
(gr) 8.4

Se — 78.96 (131.1) — 34

0	1.10	1	5.58					
0	1.16	2	6.54					
–2								
+4	.48	4	.46	.34				
+6	.40	4	.27	.29				

$ 15.50–60.00/kg

NATIVE Se 100 SE
SELENOLITE (?) 71.2 GU
PENROSEITE 68.4 CL
CHALCOMENITE 34.2 TI

Y — 88.92 (147.6) — 39

0	1.75	8	22.5					
0	1.80	12	24.4					
+3	.92	6	3.26	.66	967	20.6	Y+3 1.02	
							Y+3 1.13	

4d1-4f0-5s2

$ 5.00/gm

THALENITE 51.4 SAMARSKITE 5.5
XENOTIME 48.4 MONAZITE 1.9
YTTROFLUORITE 13.7 FERGUSONITE < 36
EUXENITE 12.2 in ALLANITE

103 ▲ 42.87 ▲ 1.3

Zr — 91.22 (151.4) — 40

0	1.55	8	15.6					
0	1.60	12	17.2					
+4	.79	8	2.07	.56	1980	33.83	Zr+4 1.08	
+4	.82	8	2.31	.58				

4d2-4f0-5s2

$ 33.20/kg

BADDELEYITE 72.2 in PYROCHLORE 4.2
ZIRCON 49.7 EUDIALITE
ZIRKELITE 39.2 LAVENITE
CATAPLEITE ± 23 in THORTVEITITE

125 ▲ 115 ▲ -84.29 ▲ 43.31 ▲ 9.18

Nb — 92.91 (154.2) — 41

0	1.43	8	12.3					
0	1.47	12	13.3					
+4	.74	6	1.70	.53				
+4	.69	6	1.38	.49	3150	49.3	Nb+4 1.02	
							Nb+5 1.04	

4d4-4f0-5s1

$ 0.40–0.60/gm

COLUMBITE 42.0 in PEROVSKITE 18.2
PYROCHLORE 32.2 ILMENORUTILE
SAMARSKITE 26.4 in ZIRCON 1.6
MOSSITE 24.2 in SPHENE

184.5 ▲ 173.7 ▲ -127.32 ▲ 44.49 ▲ 8.3

Mo — 95.95 (159.2) — 42

0	1.36	8	10.5					
0	1.40	12	11.5					
+4	.70	6	1.44	.50	2170			
+6	.59	4	.86	.42	4930			
+6	.62	6	1.00	.44				

4d5-4f

$ 22.00–27.50/kg

MOLYBDENITE 59.9 UMOHO
POWELLITE 44.7 in SCH
FERRIMOLYBDITE 40.2 JORDIS
WULFENITE 26.4 MOLYBD

155.5 ▲ 144.2 ▲ -105.70 ▲ 4

In — 114.82 (190.60) — 49

0	1.50	8	14.1					
0	1.55	12	15.6					
+3	.81	6	2.23	58	1170	27.91	In+3 1.09	

4f0-5s2-5p1

$ 0.38–0.90/gm

TAPIOLITE 1-50 ppm SPHALERITE 700 ppm
COLUMBITE 10-100 ppm CYLINDRITE
VESUVIANITE 1-10 ppm SIDERITE
GERMANITE 1500 ppm AMPHIBOLE 1.1

58.2 ▲ 49.6 ▲ -36.36 ▲ 41.51 ▲ 12.5

Sn — 118.70 (197.04) — 50

0	1.40	4	11.5					
0	1.59	12	16.8					
–4	2.15		41.6					
+2	.93	6	3.37	.67	526	14.52	Sn+4 1.01	
+4	.71	6	1.50	.51	2080	40.57		

4f0-5s2-5p2

$ 0.95–2.29/kg

NATIVE Sn 100 STANNITE 27.4
CASSITERITE 72.9 CYLINDRITE 25.7
NORDENSKIÖLDINE 42.3 in SPHALERITE
TEALLITE 30.5 in GALENA

72 ▲ 64 ▲ -47.6 ▲ 40.25 ▲ 12.3

Sb — 121.76 (202.12) — 51

0	1.45	3	12.8					
0	1.62	12	17.8					
+3	.76	6	1.84	.54	1022	24.83	Sb 1.36	
+3	.59	4	.86	.42	3180	55.7	Sb+3 0.98	
+5	.62	6	1.00	.44			1.24	

4f0-5s2-5p3

$ 0.59–1.41/kg

NATIVE Sb 100 TETRAHEDRITE 24.9
SENARMONTITE 83.5 PYRARGYRITE 21.5
STIBNITE 71.7 SCHETELIGITE 6.5
ROMEITE 52.8 in GALENA

60.8 ▲ 51.1 ▲ -37.46 ▲ 43.06 ▲ 10.5

Te — 127.61 (211.83) — 52

0	1.43	2	12.3					
–2	2.11		39.4					
+4	.70	6	1.44	.50				
+6	.53	4	.62	.38				
+6	.56	6	.74	.40				

$ 7.70–20.00/kg

NATIVE Te 96.9 TE
TELLURITE 78.7 HE
SYLVANITE 61.0 in
CALAVERITE 57.2 in

47.6 ▲ 38.1 ▲ -27.93 ▲

La — 138.92 (230.61)

0	1.81	8	24.8					
0	1.88	12	27.8					
+3	1.18	8	6.88	.84	900	19.2	La+3 1.25	
							La+3 1.30	

4f0-5s2-5p6-5d1-5f0-6s2

Ce — 140.13 (232.62)

0	1.76	8	22.8					
0	1.82	12	25.3					
+3	1.07	8	5.13	.76	922	19.7	Ce+3 1.20	
+3	1.11	8	5.73	.79				
+4	.94	6	3.48	.67			Ce+4 1.24	

4f1-5s2-5p6-5d1-5f0-6s2

Pr — 140.92 (233.93)

0	1.77	8	23.2					
0	1.83	12	25.7					
+3	1.06	8	4.99	.76	925			
+3	1.10	8	5.58	.79				
+4	.92	6	3.26	.66				

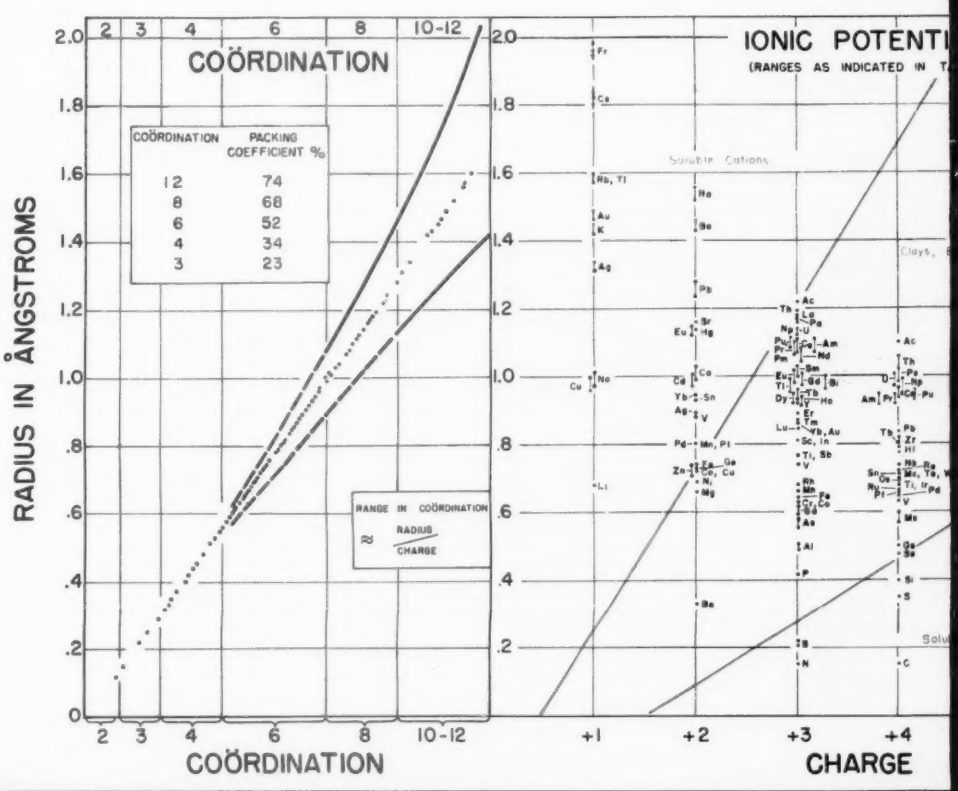
4f2-5s2-5p6-5d1-5f0-6s2

Nd — 144.27 (239.49)

0	1.77	8	23.2					
0	1.82	12	25.3					
+3	1.04	6	4.71	.74	930			
+3	1.08	8	5.28	.77				

4f3-5s2-5p6-5

6	7	8
RO_3 RH	R_2O_7	



F 19.00 (31.54)

0	.73	1	1.63	1s2-2s2-2p5			9	1/2 100
-1	1.36	2	10.5		95			
+7	.08		.0021			184.0	F 0.64T	

$ 6.30-6.90/kg

WEBERITE 57.6[1] TOPAZ 20.7
CRYOLITE 54.0 FLUORAPATITE 3.5
FLUORITE 45.0 in AMPHIBOLES & MICAS
GEARKSUTITE 40.0 in TOURMALINE (F_2) 48.6

9

ENSTATITE 46.2
HEMATITE 30.1
ARSENOLITE 24.3
CUPRITE 11.2
(O_2) 49.00 ▲ < 0.0002

Cl 35.457 (58.859)

0	.99	1	4.06	3s2-3p5				3/2 75.53
-1	1.81	4	24.8		60		Cl 0.99T	
+5	.32	4	.14	.23		67.4		
+7	.25	3	.065	.18		113.7		

$ 0.07-0.66/kg

HALITE 60.7 SODALITE 7.3
ATACAMITE 16.5 CHLORAPATITE 3.9
CALOMEL 15.0 VANADINITE 2.5
BORACITE 9.1[2] PYROMORPHITE 2.4
(Cl_2) 53.29

17

SYLVITE 63.1 CARNALLITE 24.7
HALOTRICHITE 14.4 KAINITE 12.6
SALAMMONIAC 10.3 BISCHOFITE 11.9
TACHYHYDRITE 9.6 BISHOFITE 11.9
ERYTHROSIDERITE 9.4 CARNALLITE 8.9
LAUTARITE 8.2 KAINITE 8.4
CHLORARGYRITE 7.5 TACHYHYDRITE 7.7
CHLORAPATITE 6.8 ERYTHROSIDERITE 6.4
CHLORITOID 6.4 LAUTARITE 5.8
CHLORITE 5.8 CHLORARGYRITE 5.1
CHLORITOID 4.8
CHLORITE 4.4

Mn 54.94 (91.20)

0	1.30	12	9.20	3d5-4s2			Mn+2 (0.85)F 0.95 (1.13)S	55 5/2 100
+2	.80	6	2.14	.57	560	15.7		
+3	.66	6	1.20	.47	1300	32?		
+4	.57	4	.78	.41	2680	52?	Mn+3 0.98 Mn+4 1.03	
+6	.60	6	.90	.43		~122		
+7	.44	4	.36	.31				

ALABANDITE 63.0 RHODOCHROSITE 36.3
PYROLUSITE 61.6 TRIPLITE 27.9
RHODONITE 41.9 FRANKLINITE 12.1

25 68.34 ▲ 58.23 ▲ -42.682 ▲ 41.49 ▲ 7.59 13.3

Fe 55.85 (92.71)

0	1.24	8	7.99	3d6-4s2			Fe+2 0.81F Fe+2 0.90 Fe+3 1.10S Fe+3 0.81F Fe+3 0.92	54 5.9
0	1.27	12	8.58					56 91.6
+2	.74	6	1.70	.53	580	16.24		57 2.2
+3	.64	6	1.10	.46	1280			58 0.33

NATIVE ter. Fe. 95.1 PYRITE 44.1
HEMATITE 69.9 SIDERITE 35.0
MAGNETITE 63.3 JAROSITE 31.4
LAWRENCITE 44.1 GLAUCONITE ± 14

26 96.68 ▲ 85.76 ▲ -62.861 ▲ 43.11 ▲ 6.49 2.5

Co 58.94 (97.84)

0	1.22	8	7.61	3d7-4s2				59 7/2 100
0	1.26	12	8.38				Co+2 0.82F Co+2 0.90 Co+3 1.10S Co+3 3.65	
+2	.72	6	1.56	.51	620	17.3		
+3	.63	6	1.05	.45	1320			

COBALTOCALCITE 45.7 BIEBERITE 17.0
LINNAEITE 44.7 SKUTTERUDITE 11.3
COBALTITE 30.0 in PYRITE < 1.3
ERYTHRITE 23.9 in SPHALERITE 0.3

27 105 ▲ 94 ▲ -68.9 ▲ 42.88 ▲ 6.8 37

Ni 58.71 (97.46)

0	1.21	8	7					
0	1.24	12	7					
+2	.69	6	1					

ter. NICK
MILLERIT
NICCOLIT

28 PENTLAN

Br 79.916 (132.66)

0	.14	1	6.20	4p5				79 3/2 50.6
-1	1.50	4	31.5		55			81 3/2 49.4
+5	.45	4	.38	.32				
+7	.37	4	.21	.26		103.5	Br 1.11T	

$ 0.69-1.66/kg

BROMYRITE 31.0 in CARNALLITE 0.12
in LABRADORITE 20 ppm in SYLVITE
EMBOLITE in PHOSGENITE ?
in HALLOYSITE 12 ppm

35 7.34 ▲ 0.75 ▲ -0.551 ▲ 58.64 ▲ 36.4 6.6

SELEN-TELLURIUM 29.3
71.2 GUANAJUATITE 28.0
CLAUSTHALITE 27.6
4.2 TIEMANNITE 27.1
(hes) 10.0

Tc [99]* (164.34)

0				4d6-4f0-5s1				
+7	.53	4	.62		.38			95?
+7	.56	6	.74		.40			

probably does not occur in nature

43 9

Ru 101.1 (167.8)

0	1.28	8	8.78	4d7-4f0-5s1				96 5.6
0	1.32	12	9.63					98 1.9
+4	.67	6	1.26	.48	2180		Ru+4 1.01	99 5/2 12.7
								100 12.7
								101 5/2 17.0
								102 31.5
								104 18.6

$ 4.00-6.50/gm

LAURITE 61.1 in CHROMITE < .5 ppm
in SISERSKITE 11.1 in ILMENITE .004 ppm
in AUROSMIRIDIUM 3.5

44 160 ▲ 149 ▲ -109.2 ▲ 44.87 ▲ 6.9 2.5

Rh 102.91 (170.83)

0	1.30	8	9.20	4d8-4f0-5s1				103 1/2 100
0	1.34	12	10.1					
+3	.68	6	1.32	.49	1250		Rh+3 0.99	

$ 5.00-8.00/gm

RHODITE in SPERRYLITE 1.7
in SISERSKITE 11.3 in PLATINUM 0.6
in PLATINIRIDIUM 6.9 in CHROMITE 0.5 ppm
in IRIDOSMINE 4.5 in ALLOPALLADIUM

45 138 ▲ 127 ▲ -93.09 ▲ 44.39 ▲ 7.6 150

Pd 106.4 (176.6)

0	1.33	8	9					
0	1.37	12	10					
+2	.80	6	2					
+4	.65	6	1					

$ 2.80/gm

NATIVE
STIBIOPA
in PLAT

46 POTARIT 93 ▲

I 126.91 (210.67)

0	1.33	1	9.86	4f0-5s2-5p5				127 5/2 100
0	1.35	2	10.3					
-1	2.20		44.6					
+5	.59	4	.86	.42	45			
+5	.62	6	1.00	.44			I 1.28T	
+7	.48	4	.46	.34		90.2		

$ 1.16-2.34/gm

MARSHITE in BROMYRITE 15.1
LAUTARITE in MALACHITE
IODYRITE 54.1 in PHLOGOPITE
DIETZEITE 44.4 in VESUVIANITE

53 14.88 ▲ 4.63 ▲ -3.394 ▲ 62.26 ▲ 27.9 6.3

TEINITE 36.8
HESSITE 36.4
in GALENA 1000 ppm
in GOLD
7.93 ▲ 43.64 ▲ 11.88 4.6

Pm [147]* (244.02)

+3	1.02	6	4.44	4f4-5s2-5p6-5d1-5f0-6s2				
+3	1.06	8	4.99	.73	.76	934		

KEY

Element
S - SIDEROPHILE
C - CHALCOPHILE
A - ATMOPHILE
L - LITHOPHILE
B - BIOPHILE and LITHOPHILE

Atomic Weight
[#] Mass of isotope of longest half life; (#)* - Mass of isotope of best known half life

(#) Weight of one atom x 10^{-24} grams

ABUNDANCES
in ppm unless indicated otherwise
(FOR SPECIFIC ROCK TYPES, SEE ABBREVIATIONS)
Arithmetical Average — A, b — Number of Analyses
C — Standard Deviation (variance ratio in brackets)
General overall average —
Specific { intrusive ▲ Gi ▲ / extrusive ▼ Wi ▼
IGNEOUS ROCK TYPES
GRAMS/TON

Deep Sea Sediments	Ocean (Transfer Percentag
Shales	Metamorphic Rocks
Sandstones	Other
Carbonates	Other

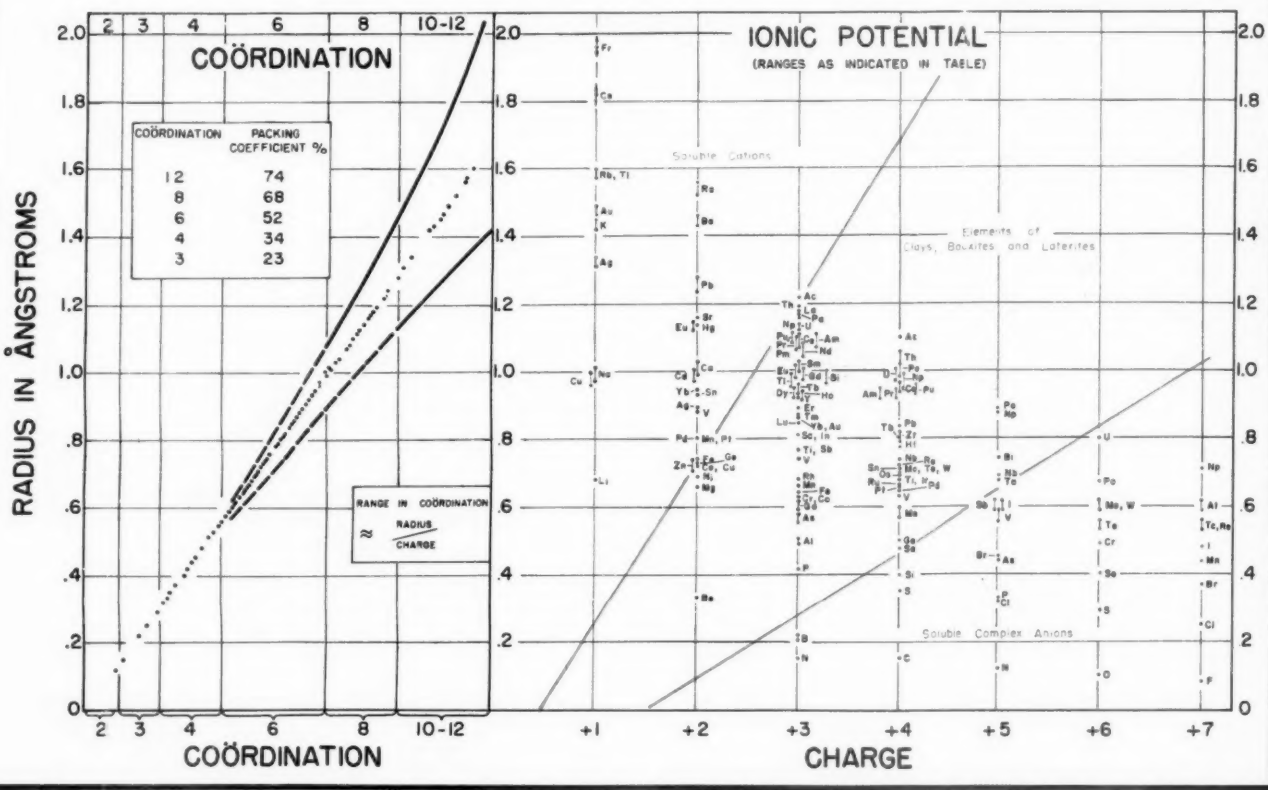
Char | Radius(Å) (Radii listed as) | Coord | Volume

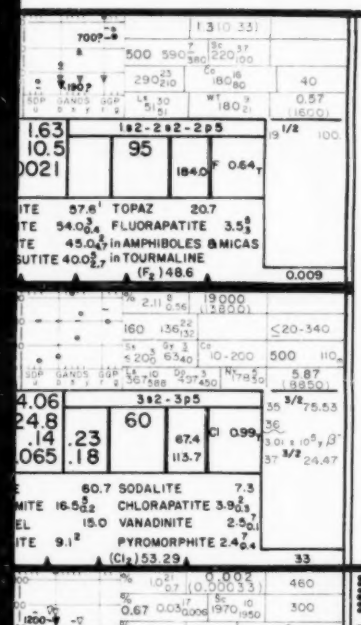
Electrons in Each Quantum Group
QUANTUM GROUPS 1s thru 7s CORRESPOND TO SHELLS K thru
QUANTUM GROUPS FILLED BEFORE 1st GROUP LISTED AND EMPTY AFTER LAST GROUP LISTED (5g zero throughout)

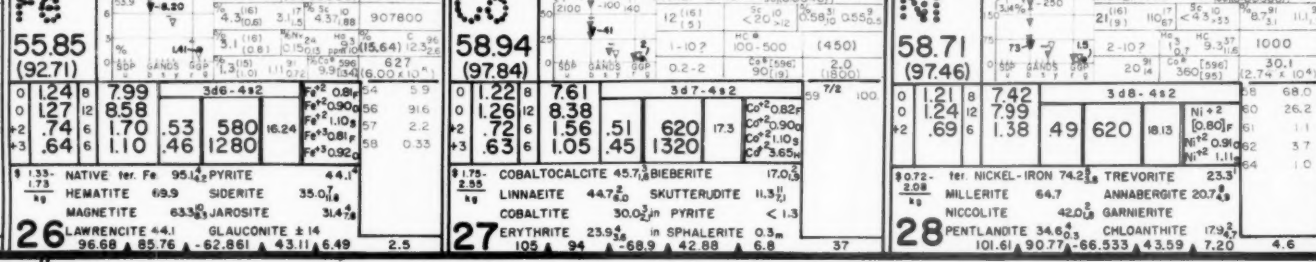
7

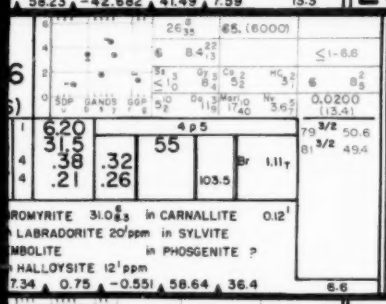
R_2O_7

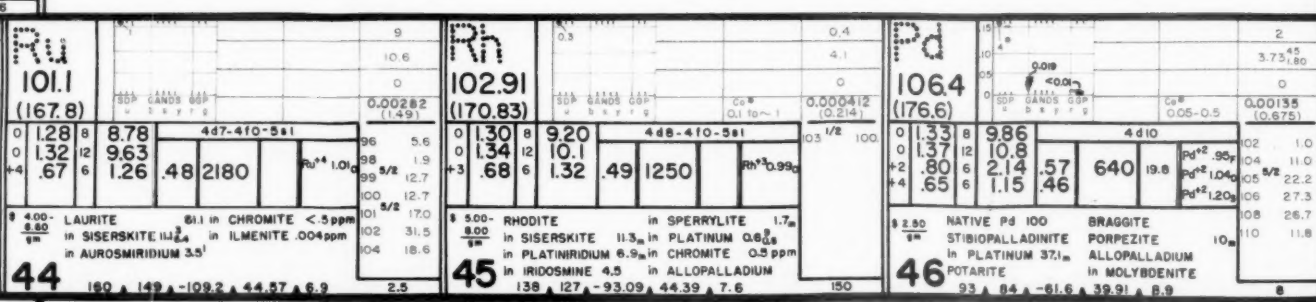
8

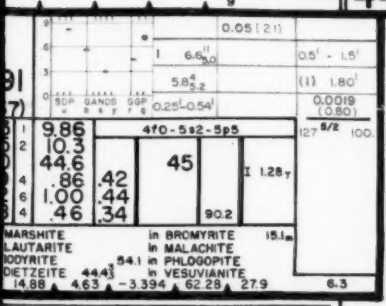


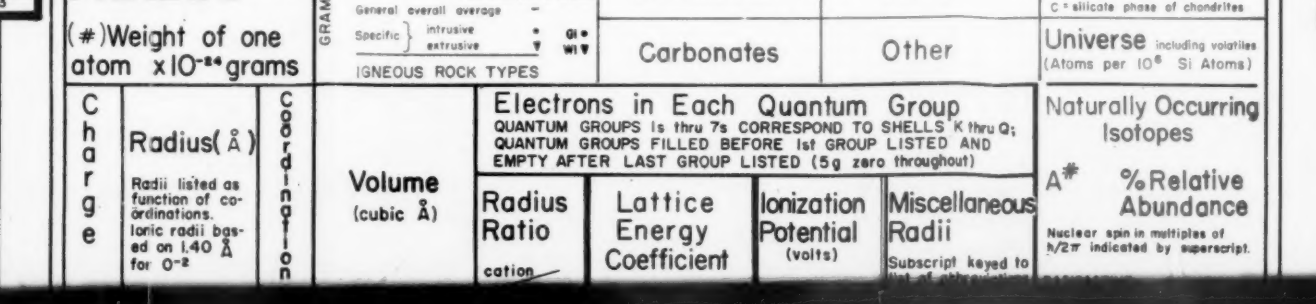












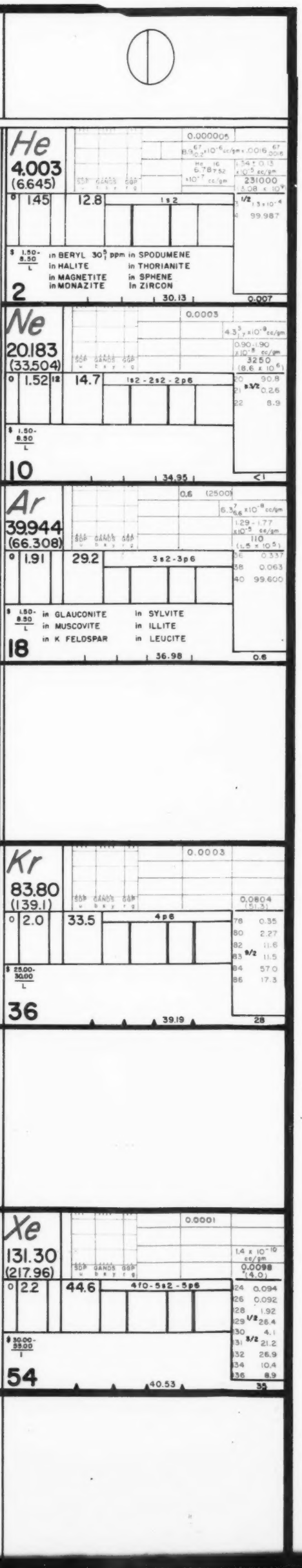
KEY

Element — S - SIDEROPHILE, C - CHALCOPHILE, A - ATMOPHILE, L - LITHOPHILE, B - BIOPHILE and LITHOPHILE	ABUNDANCES in ppm unless indicated otherwise (FOR SPECIFIC ROCK TYPES SEE ABBREVIATIONS)	Deep Sea Sediments	Ocean (Transfer Percentage)	Meteoritic Sulfides (C = sulfide phase of chondrites)
Atomic Weight [#] Mass of isotope of longest half life; [#]* - Mass of isotope of best known half life	Arithmetical Average A, b - Number of Analyses, C - Standard Deviation (variance ratio in brackets)	Shales	Metamorphic Rocks	Meteoritic Irons (C = iron phase of chondrites)
(#) Weight of one atom x 10^{-24} grams	General overall average –; Specific: intrusive ▪ GI●, extrusive ▼ WI▼	Sandstones	Other	Chondrites (C = silicate phase of chondrites)
GRAMS/TON	IGNEOUS ROCK TYPES	Carbonates	Other	Universe including volatiles (Atoms per 10^6 Si Atoms)

Charge	Radius(Å)	Coordination	Volume (cubic Å)	Electrons in Each Quantum Group	Naturally Occurring Isotopes
	Radii listed as function of coordinations. Ionic radii based on 1.40 Å for O^{-2}			QUANTUM GROUPS 1s thru 7s CORRESPOND TO SHELLS K thru Q; QUANTUM GROUPS FILLED BEFORE 1st GROUP LISTED AND EMPTY AFTER LAST GROUP LISTED (5g zero throughout)	A# % Relative Abundance

Radius Ratio	Lattice Energy Coefficient	Ionization Potential (volts)	Miscellaneous Radii
cation /			Subscript keyed to

Nuclear spin in multiples of $h/2\pi$ indicated by superscript.



SERIES

ELECTROMOTIVE

Standard electrode potentials at 25° C

$Li^{+1} + e_0^- \rightleftharpoons Li$	−3.01 ± icv	$Cu^{+2} + 2e_0^- \rightleftharpoons Cu$	+0.34 ± icv
$Rb^{+1} + e_0^- \rightleftharpoons Rb$	−2.98 ± icv	$\frac{1}{2}O_2 + H_2O + 2e_0^- \rightleftharpoons 2OH^-$	+0.401 ± imv
$Cs^{+1} + e_0^- \rightleftharpoons Cs$	−2.92 ± icv	$Cu^{+1} + e_0^- \rightleftharpoons Cu$	+0.52 ± icv
$K^{+1} + e_0^- \rightleftharpoons K$	−2.92 ± icv	$I_2 + 2e_0^- \rightleftharpoons 2I^-$	+0.536 ± imv
$Ba^{+2} + 2e_0^- \rightleftharpoons Ba$	−2.92 ± icv	$Te^{+4} + 4e_0^- \rightleftharpoons Te$	+0.56 ± icv
$Sr^{+2} + 2e_0^- \rightleftharpoons Sr$	−2.89 ± icv	$Po^{+3} + 3e_0^- \rightleftharpoons Po$	+0.65 ± ?v
$Ca^{+2} + 2e_0^- \rightleftharpoons Ca$	−2.84 ± icv	$Rh^{+2} + 2e_0^- \rightleftharpoons Rh$	+0.6 ± ?v
$Na^{+1} + e_0^- \rightleftharpoons Na$	−2.713 ± imv	$Hg_2^{+2} + 2e_0^- \rightleftharpoons 2Hg$	+0.798 ± imv
$La^{+3} + 3e_0^- \rightleftharpoons La$	−2.4 ± ?v	$Ag^{+1} + e_0^- \rightleftharpoons Ag$	+0.799 ± imv
$Mg^{+2} + 2e_0^- \rightleftharpoons Mg$	−2.38 ± icv	$Pd^{+2} + 2e_0^- \rightleftharpoons Pd$	+0.83 ± ?v
$Th^{+4} + 4e_0^- \rightleftharpoons Th$	−2.1 ± ?v	$Ir^{+3} + 3e_0^- \rightleftharpoons Ir$	+1.0 ± ?v
$Ti^{+2} + 2e_0^- \rightleftharpoons Ti$	−1.75 ± ?v	$Br_2(l) + 2e_0^- \rightleftharpoons 2Br^-$	+1.066 ± imv
$Be^{+2} + 2e_0^- \rightleftharpoons Be$	−1.70 ± icv	$Pt^{+2} + 2e_0^- \rightleftharpoons Pt$	+1.2 ± ?v
$Al^{+3} + 3e_0^- \rightleftharpoons Al$	−1.66 ± icv	$Cl_2 + 2e_0^- \rightleftharpoons 2Cl^-$	+1.358 ± imv
$V^{+2} + 2e_0^- \rightleftharpoons V$	−1.5 ± ?v	$Au^{+3} + 3e_0^- \rightleftharpoons Au$	+1.42 ± ?v
$Mn^{+2} + 2e_0^- \rightleftharpoons Mn$	−1.05 ± ?v	$Au^{+1} + e_0^- \rightleftharpoons Au$	+1.7 ± ?v
$Te + 2e_0^- \rightleftharpoons Te^{-2}$	−0.92 ± ?v	$F_2 + 2e_0^- \rightleftharpoons 2F^-$	+2.85 ± icv
$Se + 2e_0^- \rightleftharpoons Se^{-2}$	−0.78 ± icv		
$Zn^{+2} + 2e_0^- \rightleftharpoons Zn$	−0.763 ± imv		
$Cr^{+3} + 3e_0^- \rightleftharpoons Cr$	−0.71 ± ?v		
$Ga^{+3} + 3e_0^- \rightleftharpoons Ga$	−0.52 ± icv		
$S + 2e_0^- \rightleftharpoons S^{-2}$	−0.51 ± icv		
$Fe^{+2} + 2e_0^- \rightleftharpoons Fe$	−0.44 ± icv		
$Cd^{+2} + 2e_0^- \rightleftharpoons Cd$	−0.402 ± imv		
$In^{+3} + 3e_0^- \rightleftharpoons In$	−0.34 ± icv		
$Tl^{+1} + e_0^- \rightleftharpoons Tl$	−0.335 ± imv		
$Co^{+2} + 2e_0^- \rightleftharpoons Co$	−0.27 ± icv		
$Ni^{+2} + 2e_0^- \rightleftharpoons Ni$	−0.23 ± icv		
$Mo^{+3} + 3e_0^- \rightleftharpoons Mo$	−0.2 ± ?v		
$Sn^{+2} + 2e_0^- \rightleftharpoons Sn$	−0.140 ± imv		
$Pb^{+2} + 2e_0^- \rightleftharpoons Pb$	−0.126 ± imv		
$D^{+1} + e_0^- \rightleftharpoons \frac{1}{2}D_2$	−0.003 ± icv		

v = volts
cv = centivolts
mv = millivolts

STANDARD OXIDATION-REDUCTION POTENTIALS AT 25°C.

Reaction	e_0 volts
$Cr^{+3} + e_0^- \rightleftharpoons Cr^{+2}$	−0.41
$Ti^{+3} + e_0^- \rightleftharpoons Ti^{+2}$	−0.37 ± 0.01
$V^{+3} + e_0^- \rightleftharpoons V^{+2}$	−0.20
$Sn^{+4} + 2e_0^- \rightleftharpoons Sn^{+2}$	0.154 ± 0.001
$Cu^{+2} + e_0^- \rightleftharpoons Cu^{+1}$	0.167 ± 0.001
$I_3^{-1} + 2e_0^- \rightleftharpoons 3I^{-1}$	0.535
$Fe^{+3} + e_0^- \rightleftharpoons Fe^{+2}$	0.771 ± 0.0005
$2Hg^{+2} + 2e_0^- \rightleftharpoons Hg_2^{+2}$	0.905 ± 0.001
$Tl^{+3} + 2e_0^- \rightleftharpoons Tl^{+1}$	1.25
$Mn^{+3} + e_0^- \rightleftharpoons Mn^{+2}$	1.51
$Ce^{+4} + e_0^- \rightleftharpoons Ce^{+3}$	1.610 ± 0.001
$H_2O_2 + 2H^{+1} + 2e_0^- \rightleftharpoons 2H_2O$	1.77
$Co^{+3} + e_0^- \rightleftharpoons Co^{+2}$	1.842 ± 0.001

ELECTROCHEMICAL EQUIVALENTS

(Milligrams per Coulomb)

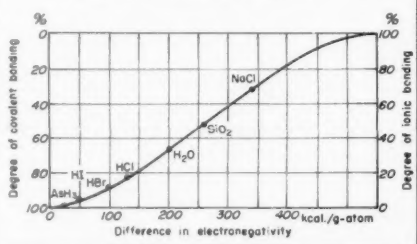
H^{+1}	0.010446	Po^{+6}	0.36269
D_2^{+1}	0.020878	Cl^{-1}	0.36743
N^{+5}	0.029032	Ta^{+5}	0.37488
C^{+4}	0.031113	In^{+3}	0.39641
B^{+3}	0.03737	K^{+1}	0.40514
He^{0}	0.04147	U^{+6}	0.41117
Be^{+2}	0.04674	A^{+0}	0.41393
N^{+3}	0.048387	Sb^{+3}	0.42059
S^{+6}	0.05537	Bi^{+5}	0.43316
C^{+2}	0.06223	Sr^{+2}	0.45404
P^{+5}	0.06421	Hf^{+4}	0.46269
Li^{+1}	0.07192	La^{+3}	0.47986
Si^{+4}	0.07269	Ce^{+3}	0.48404
O^{-2}	0.082902	Pr^{+3}	0.48677
S^{+4}	0.08306	Os^{+4}	0.49611
Cr^{+6}	0.08983	Nd^{+3}	0.49834
Al^{+3}	0.09316	Ir^{+4}	0.50026
V^{+5}	0.10560	Pm^{+3}	0.50432
Ti^{+4}	0.12409	Pt^{+4}	0.50578
Mg^{+2}	0.12601	Sm^{+3}	0.51962
Se^{+6}	0.13637	Eu^{+3}	0.52504
Mn^{+4}	0.14230	Pb^{+4}	0.53681
Tc^{+7}	0.14478	Gd^{+3}	0.54179
As^{+5}	0.15254	Tb^{+3}	0.54991
Sc^{+3}	0.15579	Dy^{+3}	0.56069
Mo^{+6}	0.16580	Ho^{+3}	0.56974
S^{-2}	0.16611	Er^{+3}	0.57907
Cr^{+3}	0.17965	Cd^{+2}	0.58244
Ge^{+4}	0.18808	Tm^{+3}	0.58515
Nb^{+5}	0.19256	Yb^{+3}	0.59772
Fe^{+3}	0.19291	Pa^{+5}	0.59845
F^{-1}	0.19689	Th^{+4}	0.60135
Ca^{+2}	0.20767	Lu^{+3}	0.60446
Ne^{0}	0.20915	Sn^{+2}	0.61503
Te^{+6}	0.22040	Cu^{+1}	0.65876
Zr^{+4}	0.23632	Au^{+3}	0.68117
Na^{+1}	0.23831	Tl^{+3}	0.70601
Ga^{+3}	0.24083	Ba^{+2}	0.71171
Sb^{+5}	0.25235	Bi^{+3}	0.72193
As^{+3}	0.25876	Ac^{+3}	0.78411
Ru^{+4}	0.26347	Br^{+1}	0.82815
Rh^{+4}	0.26661	Kr^{+0}	0.86736
Re^{+7}	0.27581	Rb^{+1}	0.88580
Pd^{+4}	0.27642	Hg^{+2}	1.03943
Mn^{+2}	0.28461	Pb^{+2}	1.07363
Fe^{+2}	0.28938	Ag^{+1}	1.11793
Ni^{+2}	0.30409	Ra^{+2}	1.17124
Co^{+2}	0.30539	I^{-1}	1.31523
Y^{+3}	0.30715	Xe^{+0}	1.36062
Sn^{+4}	0.30751	Cs^{+1}	1.37731
W^{+6}	0.31779	Au^{+1}	2.04352
Cu^{+2}	0.32938	Hg^{+1}	2.07886
Zn^{+2}	0.33876	Rn^{+0}	2.30052

ELECTRONEGATIVITY

Kilocalories/gram-atom

Cs	89	Co^{+2}	200	Mn^{+3}	260
Rb	97	Sc	200	Co^{+3}	260
K	100	Zn	208	Ge	265
Ba	115	Be	210	Sb	270
Na	118	Ta^{+5}	(210)	Si	270
Sr	125	Au^{+1}	212	Pd	—
Li	125	Hg^{+2}	215	Mo^{+6}	275
Ca	137	Nb^{+4}	215	Ni^{+3}	275
Tl^{+1}	140	U^{+6}	(215)	V^{+4}	280
La	147	In	215	B	290
Ce^{+3}	160	As^{+3}	220	As^{+5}	310
Y	160	Ni^{+2}	220	Ru^{+3}	—
Th^{+4}	(170)	Ti^{+3}	220	Mn^{+4}	310
Pb^{+2}	170	Al	220	Ir	—
Mn^{+2}	170	Tl^{+3}	230	Rh	—
Mg	174	Ga	235	Te	315
Ag^{+1}	175	Cu^{+2}	235	V^{+5}	315
Cu^{+1}	177	V^{+3}	235	P	320
Hf^{+4}	(180)	Sn^{+4}	235	H	328
Fe^{+2}	185	W^{+6}	(235)	Se	360
Ta^{+4}	190	Nb^{+5}	240	Cr^{+6}	370
Ce^{+4}	190	Rh^{+3}	240	C	370
U^{+4}	(190)	Hg^{+1}	240	I	375
Bi^{+3}	195	Pt^{+4}	240	S	385
Sb^{+3}	195	Fe	245	Br	425
Cd	195	Pb	245	N	450
Pa^{+5}	(195)	Cr^{+3}	250	Cl	460
Pt^{+2}	200	Ti^{+4}	260	O	530
Zr	200	Re^{+7}	260	F	605

Extrapolated values in parentheses



INDEX OF IONIC REPLACEMENT

atomic number = bA^{C} = charge

$_{55}Cs^{+1}$	.02	$_{30}Zn^{+2}$	.14	$_{27}Co^{+3}$	.22
$_{37}Rb^{+1}$	.03	$_{26}Fe^{+2}$	.14	$_{31}Ge^{+3}$	.22
$_{81}Tl^{+1}$	.03	$_{29}Cu^{+2}$	.14	$_{13}Al^{+3}$ (6 FOLD COORD.)	.23
$_{19}K^{+1}$	.03	$_{27}Co^{+2}$	.14	$_{4}Be^{+2}$	.24
$_{47}Ag^{+1}$	.04	$_{50}Sn^{+2}$	.14	$_{72}Hf^{+4}$	.27
$_{11}Na^{+1}$	.06	$_{28}Ni^{+2}$	.14	$_{41}Nb^{+4}$	.28
$_{29}Cu^{+1}$	.06	$_{12}Mg^{+2}$	.14	$_{74}W^{+4}$	.28
$_{56}Ba^{+2}$	.07	$_{90}Th^{+4}$	.16	$_{42}Mo^{+4}$	.28
$_{82}Pb^{+2}$	.08	$_{92}U^{+4}$	.19	$_{22}Ti^{+4}$	.28
$_{38}Sr^{+2}$	.08	$_{40}Zr^{+4}$	.20	$_{13}Al^{+3}$ (4 FOLD COORD.)	.35
$_{20}Ca^{+2}$	.09	$_{21}Sc^{+3}$	.20	$_{83}Bi^{+5}$	.35
$_{48}Cd^{+2}$	.09	$_{49}In^{+3}$	.20	$_{5}^{+3}$	.39
$_{3}^{+1}$	.10	$_{23}V^{+3}$	.21	$_{32}Ge^{+4}$	.46
$_{57}La^{+3}$	.12	$_{25}Mn^{+3}$	.21	$_{14}Si^{+4}$	.48
$_{25}Mn^{+2}$	.13	$_{26}Fe^{+3}$	.22	$_{33}As^{+5}$	.60
$_{39}Y^{+3}$	.14	$_{24}Cr^{+3}$	.22	$_{15}P^{+5}$	.62

ENTROPIES S_0 OF IONS IN AQUEOUS SOLUTION AT 25° C.

(In cal. degree^{-1}.mol^{-1})
with reference to $S_{0,H^+1} = 0$

MnO_4^{-1}	46.7 ± 0.4	Sn^{+2}	−4.9 ± 1.0
Cs^{+1}	31.8 ± 0.6	Sr^{+2}	−7.3 ± 1.5
Mg^{+2}	31.6 ± 3	Ca^{+2}	−12.7 ± 0.6
Tl^{+1}	30.5 ± 0.4	CO_3^{-2}	−13.0 ± 1.0
NO_3^{-1}	29.9 ± 1	Cd^{+2}	−16.4 ± 1.5
Rb^{+1}	28.7 ± 0.7	Mn^{+2}	−19.1
IO_3^{-1}	28.0 ± 1.0	Zn^{+2}	−25.7 ± 1.0
NH_4^{+1}	26.6 ± 0.6	Fe^{+2}	−25.9 ± 1.0
I^{-1}	25.3	Cu^{+2}	−26.5 ± 1.0
CN^{-1}	25 ± 5	Be^{+2}	−27
K^{+1}	24.2 ± 0.2	Co^{+2}	−27
HCO_3^{-1}	22.2 ± 0.8	Ni^{+2}	−31
$H_2PO_4^{-1}$	21.6 ± 0.3	Y^{+3}	−34
Br^{-1}	19.7	Tl^{+3}	−35
Hg_2^{+2}	19.7 ± 3	In^{+3}	−42
Ag^{+1}	17.54 ± 0.15	Sb^{+3}	−43
HS^{-1}	14.9 ± 1.0	Se^{+3}	−48
Na^{+1}	14.0 ± 0.4	PO_4^{-3}	−52 ± 2
Cl^{-1}	13.50	Mn^{+3}	−59
CrO_4^{-2}	10.6 ± 1.0	As^{+3}	−60
$C_2O_4^{-2}$	9.6 ± 1.0	Rh^{+3}	−60
HPO_4^{-2}	8.7 ± 1.0	Fe^{+3}	−61 ± 5
Li^{+1}	4.7 ± 1.0	V^{+3}	−65
SO_4^{-2}	4.4 ± 0.5	Th^{+4}	−65
Pb^{+2}	3.9 ± 0.9	Cr^{+3}	−65
SO_3^{-2}	3 ± 3	U^{+4}	−67.9
OH^{-1}	2.49 ± 0.06	Ga^{+3}	−69
F^{-1}	2.3 ± 2	Al^{+3}	−76 ± 10
Ba^{+2}	2.3 ± 0.3	Te^{+4}	−79
H	0.00	Zr^{+4}	−81
		Pb^{+4}	−84
		Sn^{+4}	−95
		Nb^{+4}	−101
		W^{+4}	−103
		Mo^{+4}	−103
		Os^{+4}	−104
		Ir^{+4}	−106
		Ru^{+4}	−108
		Ti^{+4}	−109
		V^{+4}	−114
		Ge^{+4}	−157
		Si^{+4}	−177

SOLUBILITY OF SULFIDES

Hg
Ag
Cu
Bi
Cd
Pb
Zn
Ni
Co
Fe^{+2}
Mn

upper replaces lower

DYSPROSIUM	Dy	66
EINSTEINIUM	Es	99
Eka-aluminum-gallium		
Eka-boron-scandium		
Eka-cesium-francium		
Eka-iodine-astatine		
Eka-manganese-technetium		
Eka-silicon-germanium		
Eka-tantalum-protactinium		
Emanation (Em)· radon		
ERBIUM	Er	68
Erythronium-vanadium		
EUROPIUM	Eu	63
Ferrum-iron		
Florentium-promethium		
FERMIUM	Fm	100
FLUORINE	F	9
FRANCIUM	Fr	87
GADOLINIUM	Gd	64
GALLIUM	Ga	31
GERMANIUM	Ge	32
Glucin(i)um-beryllium		
GOLD	Au	79
HAFNIUM	Hf	72
HELIUM	He	2
HOLMIUM	Ho	67
Hydrargyrum-mercury		
HYDROGEN	H	1
Illinium-promethium		
INDIUM	In	49
IODINE	I	53
Ionium (Io) - Th^{230}		
IRIDIUM	Ir	77
IRON	Fe	26
Jod (J) - iodine		
Kalium-potassium		
KRYPTON	Kr	36
LANTHANUM	La	57
LEAD	Pb	82
LITHIUM	Li	3
Lutecium-lutetium		
LUTETIUM	Lu	71
MAGNESIUM	Mg	12
MANGANESE	Mn	25
Masurium-technetium		

SILICON	Si	14
SILVER	Ag	47
SODIUM	Na	11
Stannum-tin		
Stibium-antimony		
STRONTIUM	Sr	38
SULFUR	S	16
TANTALUM	Ta	73
TECHNETIUM	Tc	43
TELLURIUM	Te	52
TERBIUM	Tb	65
THALLIUM	Tl	81
THORIUM	Th	90
Thorium A (ThA) - Po^{216}		
Thorium B (ThB) - Pb^{212}		
Thorium C (ThC) - Bi^{212}		
Thorium C' (ThC') - Po^{212}		
Thorium C'' (ThC'') - Tl^{208}		
Thorium D (ThD) - Pb^{208}		
Thorium X (ThX) - Ra^{224}		
Thoron (Tn) - Rn^{220}		
THULIUM	Tm	69
TIN	Sn	50
TITANIUM	Ti	22
Tritium (T) - H^3		
TUNGSTEN	W	74
URANIUM	U	92
Uranium (I) - U (I) - U^{238}		
Uranium (II) - U (II) - U^{234}		
Uranium X_1 (UX_1) - Th^{234}		
Uranium X_2 (UX_2) - Pa^{234} metastable		
Uranium Y (UY) - Th^{231}		
Uranium Z (UZ) - Pa^{234}		
VANADIUM	V	23
Virginium-francium		
Wolfram-tungsten		
Wolframium-tungsten		
XENON	Xe	54
YTTERBIUM	Yb	70
YTTRIUM	Y	39
ZINC	Zn	30
ZIRCONIUM	Zr	40

élément
Element
elemento
элемент

poids atomique
Atomgewicht
peso atómico
атомный вес

le poids d'un atome × 10^{-24} grammes
Gewicht eines Atoms × 10^{-24} Gramm
el peso de un átomo × 10^{-24} gramos
вес одного атома × 10^{-24} граммов

abondances
Gehalte
abundancias
относительное содержание

gramme/tonne
Gramm/Tonne
gramos/tonelada
содержание в граммах на тонну

moyenne
arithmétique
Arithmetischer Durchschnitt
promedio aritmético
среднее арифметическое

A

b numéro de analyses
Anzahl der Analysen
número de análisis
количество анализов

c déviation normale
Normale Streuung
desviación normal
нормальное отклонение

▲ extrusif
extrusiv
extrusivo
эффузивные породы

● intrusif
intrusiv
intrusivo
интрузивные породы

types de roches ignées
Eruptivgesteinsarten
tipos de roca ígnea
типы магматических пород

hydrolyzate pélagique Meerhydrolysat hidrolizato pelágico глубоководные осадки	océan Ozean océano океан	sulfite météoritique Meteorsulfid sulfito meteorítico метеорный сульфид
argile schisteuse Schieferton lutita глинистый сланец	roches métamorphiques Metamorphes Gestein rocas metamórficas метаморфические породы	fer météoritique Meteoreisen hierro meteorítico метеорное железо
grès Sandstein arenisca песчаник	autre Andere otro другие	silicate météoritique Meteorsilikat silicato meteorítico метеорный силикат
carbonate Karbonat carbonato карбонат	autre Andere otro другие	univers Universum universo вселенная

charge
Ladung
carga
заряд

rayon (Å)
Radius (ang.)
radio
радиус /Å/

coördination
Koördination
coordinación
координационное число

volume
Volumen
volúmen
объем

électrons dans chaque groupe quantum
Elektronen in jeder Quantumgruppe
electrones en cada grupo cuántico
число электронов в каждой квантовой группе

rapport des rayons
Radius Verhältnis
relación de los radios
соотношение радиусов

coefficient d'énergie en treillis
Gitterenergie-Koeffizient
coeficiente de la energía de celosía
коэффициент энергии кристаллической решетки

potentiel d'ionisation (volts)
Ionisierungspotential (Volt)
potencial de ionización (voltios)
ионизационный потенциал /в вольтах/

rayons divers
Verschiedene Radien
radios diversos
различные радиусы

gamme de frais (purité de réactif)
Kostbereich (Reagenz-Reinheit)
límites de gastos (pureza del reactivo)
пределы стоимости /чистота реагента/

minéraux avec pour cent du élément contenu
% Gehalt des Elements im Mineral
minerales con porcentaje del elemento contenido
% содержания элемента в минерале

isotopes occurrent naturellement
Natürliche Isotope
isotopos que ocurren de una manera natural
изотопы, встречающиеся в природе

pour cent d'abondance relative
% relativer Gehalt
% de abundancia relativo
% относительного содержания

resort nucléaire indiqué par suscript
Kernspin angedeutet durch Strich über dem betreffenden Zeichen
resorte nuclear indicado por superescrito
ядерный спин показан надстрочным индексом

isotope radio-actif
Radioaktive Isotope
isotopo radioactivo
радиоактивный изотоп

décomposition de radiation
Strahlungszersetzung
descomposición por radiación
радиоактивный распад

demi-vie
Halbwert
media vida
полураспад

numero atomique
Atomzahl
número atómico
атомное число

chaleur de combination normale
Normale Bildungswärme
calor de formación normal
стандартная теплота образования

énergie libre de formation normale
Normale freie Bildungsenergie
energía libre de formación normal
стандартная свободная энергия образования

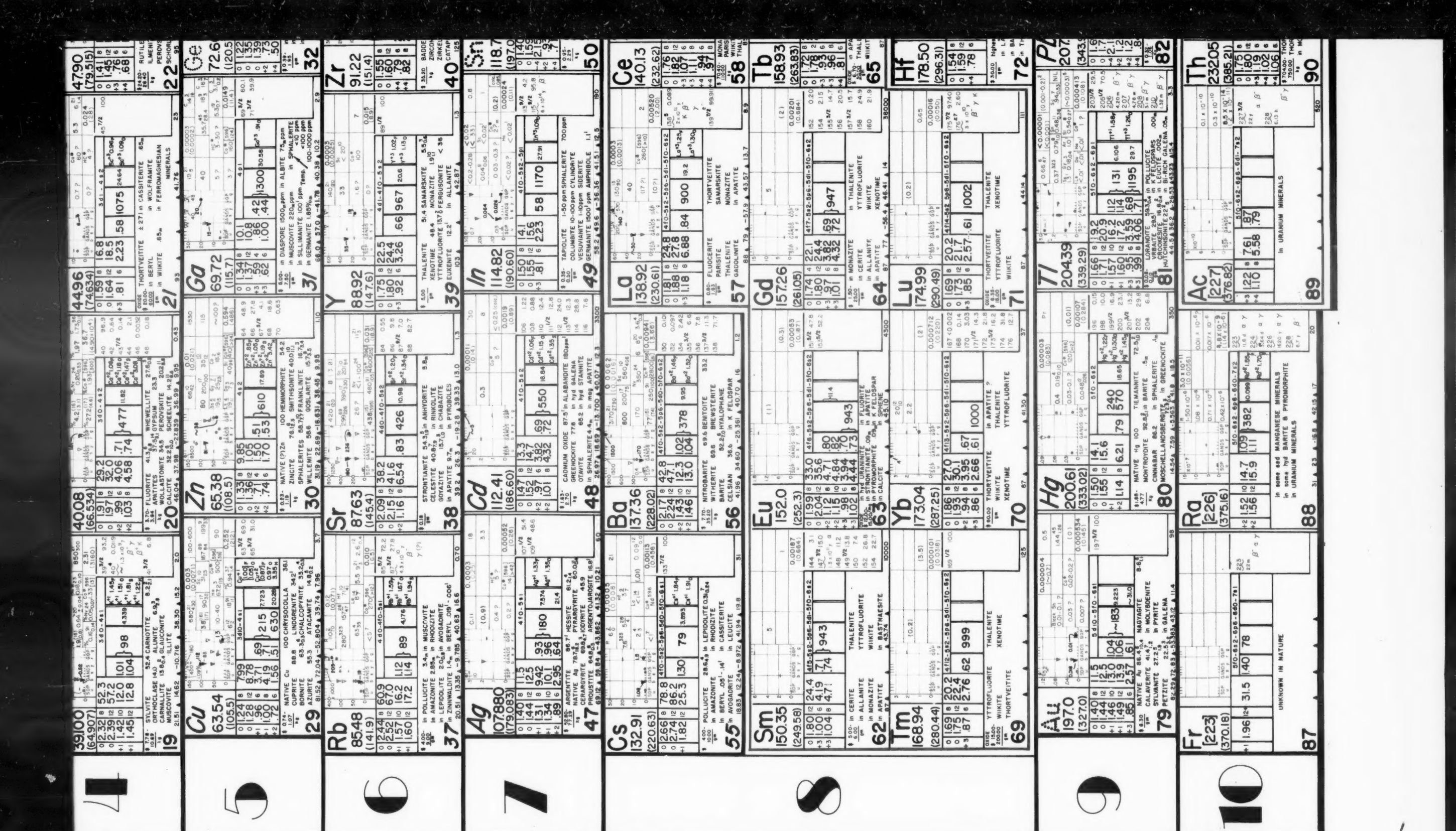
logarithme de la constante d'équilibre de formation
Logarithmus der Bildungsgleichgewichtskonstante
logarito de la constante de equilibrio de formación
логарифм постоянной равновесия образования

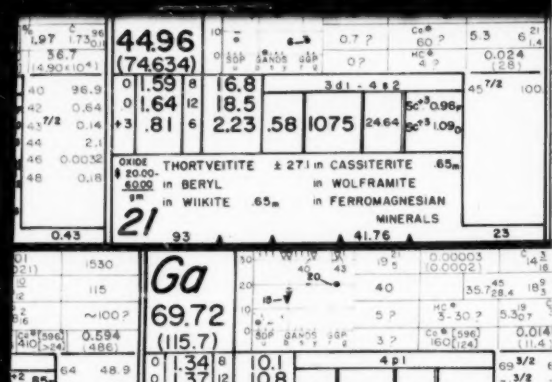
entropie à 25 degrés C. (gaz)
Entropie auf 25 Grad C. (Gas)
entropía a 25 grados C. (gas)
энтропия при 25° C. /для газообразных тел/

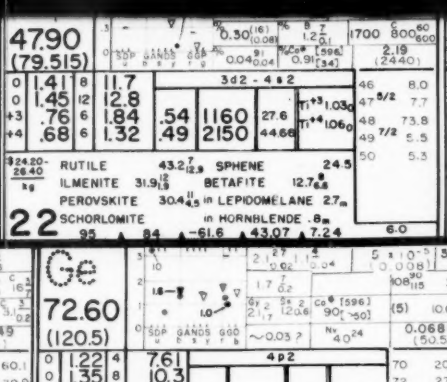
entropie à 25 degrés C. (solide)
Entropie auf 25 Grad C. (fest)
entropía a 25 grados C. (solido)
энтропия при 25° C. /для твердых тел/

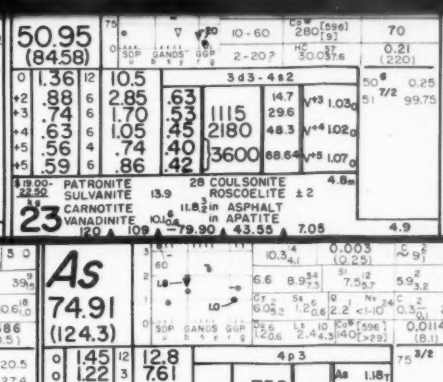
la section transversale thermale de la capture de neutrons
Querschnitt durch thermischen Neutroneneinfang
sección transversal térmica de la captación de neutrones
эффективное сечение захвата тепловых нейтронов

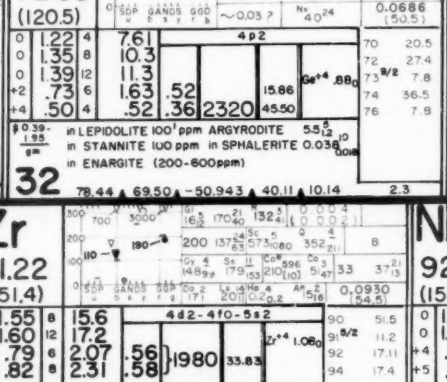
Tous les data relatifs à l'abondance sont en grammes per tonne métrique sauf quand on indique le contraire.
Alle Gehaltsangaben, wo nicht anders angegeben, in Gramm per Tonne.
Todos los datos relativos a la abundancia se indican en gramos por tonelada métrica menos cuando se indica al contrario.
Все данные об относительном содержании, за исключением отдельно указанных случаев, приведены в граммах на тонну.

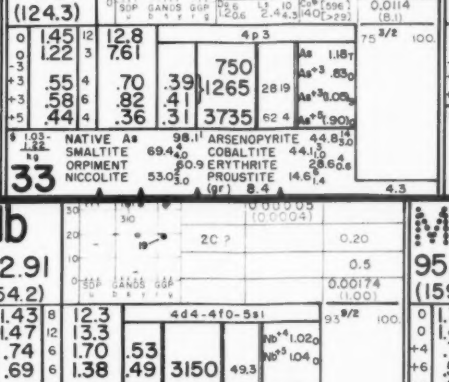

4
5
6
7
8
9
10
Ti
47.90
(79.515)
22
Zr
91.22
(151.4)
50
Hf
178.50
(296.31)
82
Th
232.05
(385.21)
90
Ce
140.13
(232.62)
58
Pr
Nd
Pm
Sm
150.35
(249.58)
62
Eu
152.0
(252.3)
63
Gd
157.26
(261.05)
64
Tb
158.93
(263.83)
65
Dy
Ho
Er
Tm
168.94
(280.44)
69
Yb
173.04
(287.25)
70
Lu
174.99
(290.49)
71
V
Cr
Mn
Fe
Co
Ni
Cu
63.54
(105.5)
29
Zn
65.38
(108.5)
30
Ga
69.72
(115.7)
31
Ge
72.6
(120.5
32
Y
88.92
(147.6)
39
Nb
Mo
Tc
Ru
Rh
Pd
Ag
107880
(179.083)
47
Cd
112.41
(186.60)
48
In
114.82
(190.60)
49
Sn
118.7
(196.7)
50
Rb
85.48
(141.9)
37
Sr
87.63
(145.4)
38
Cs
132.91
(220.63)
55
Ba
137.36
(228.02)
56
Au
197.0
(327.0)
79
Hg
200.61
(333.02)
80
Tl
20439
(339.29)
81
Pb
207.2
(343.5)
82
Bi
Fr
[223]
(370.18)
87
Ra
[226]
(375.16)
88
Ac
[227]
(376.82)
89

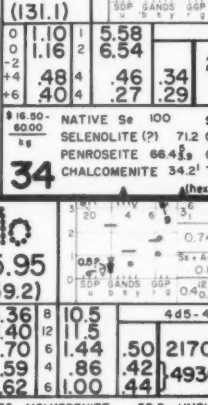


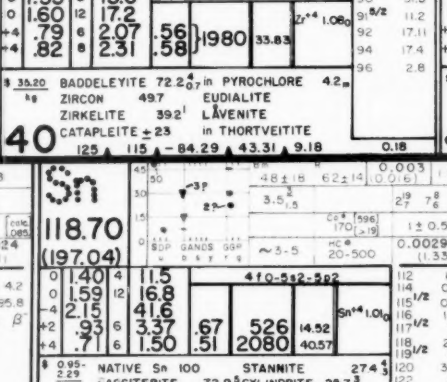


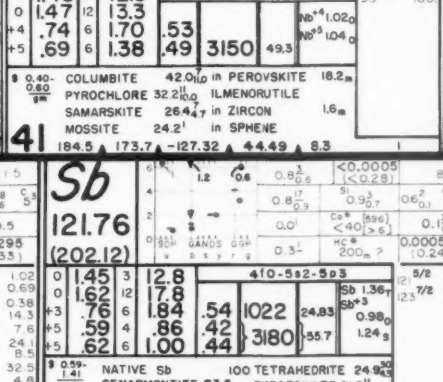


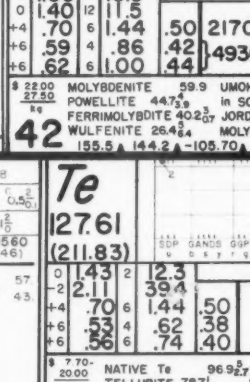


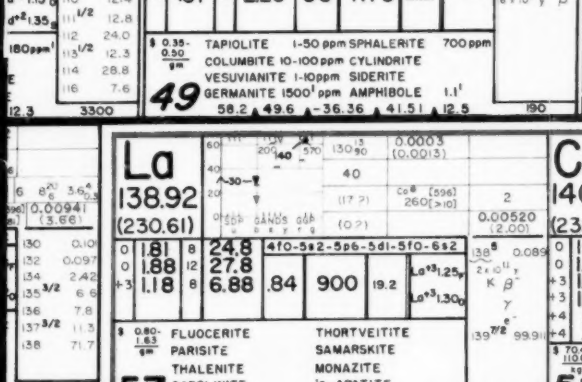


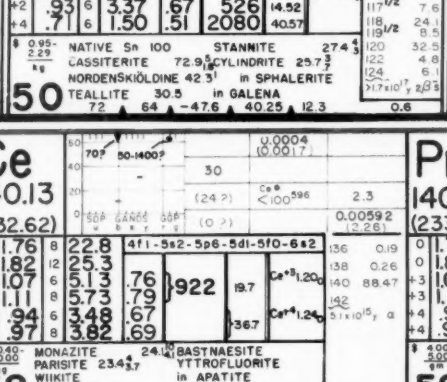


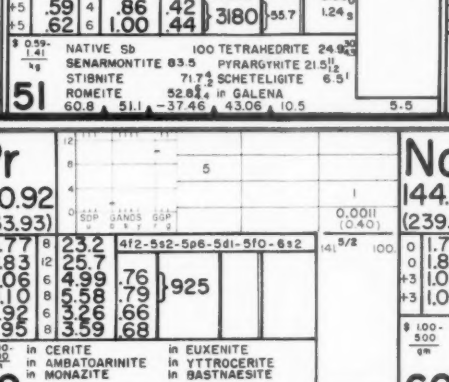


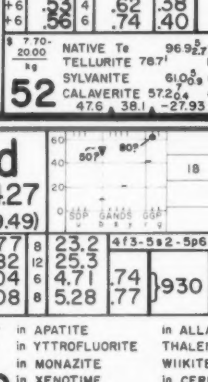


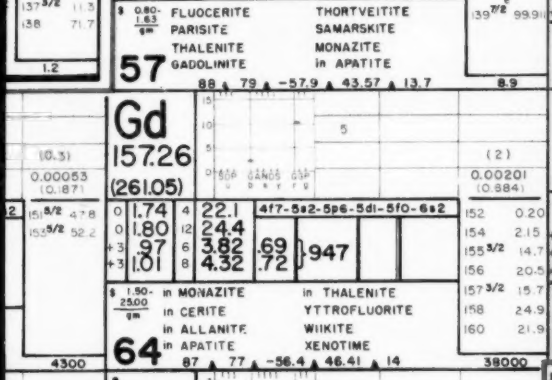


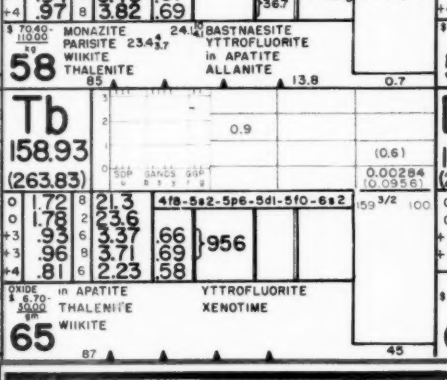


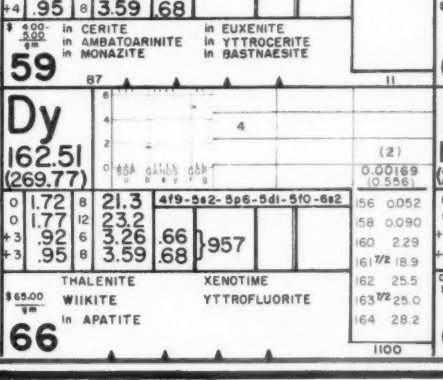


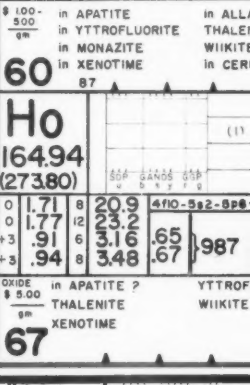


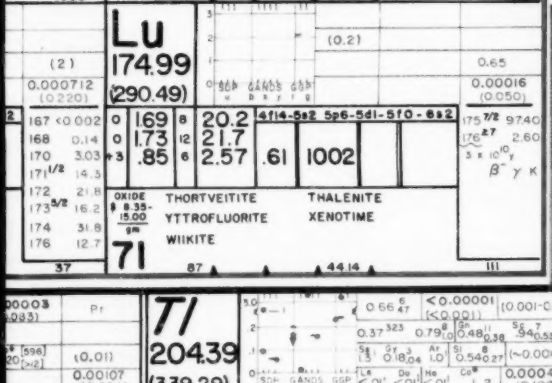


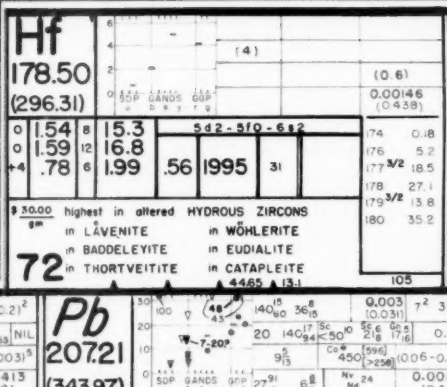


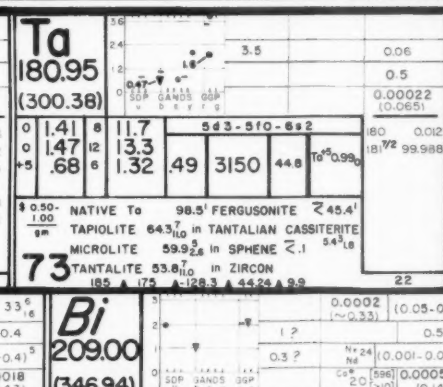


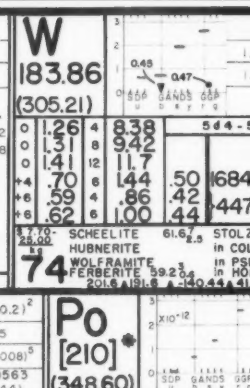


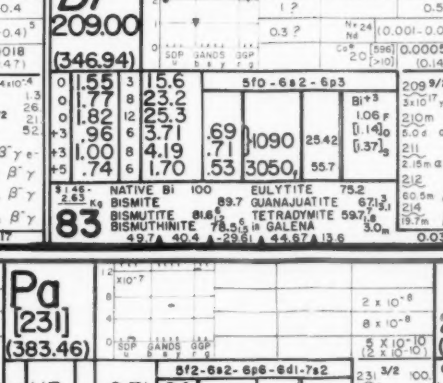


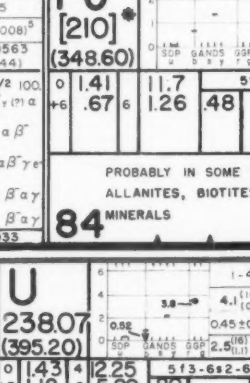


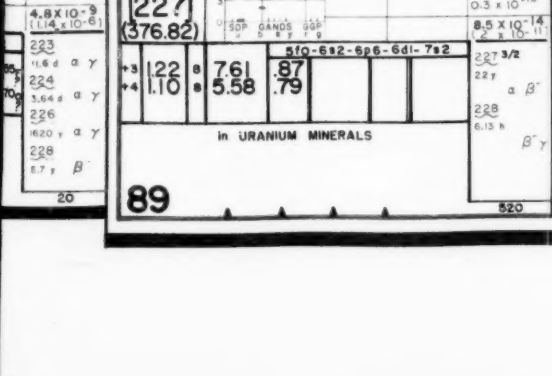


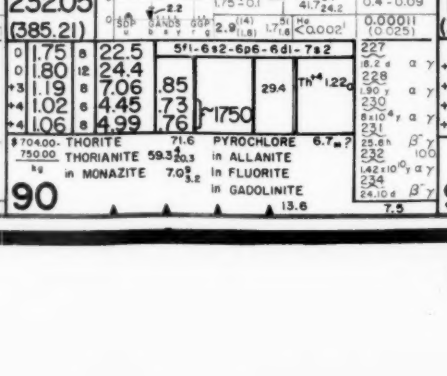


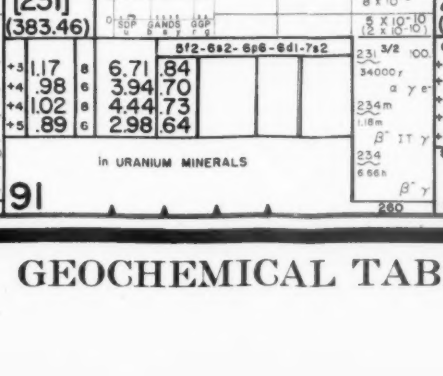


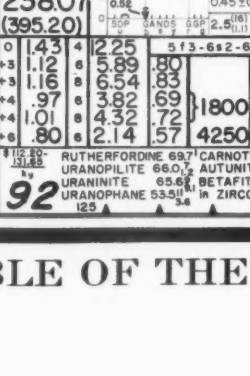




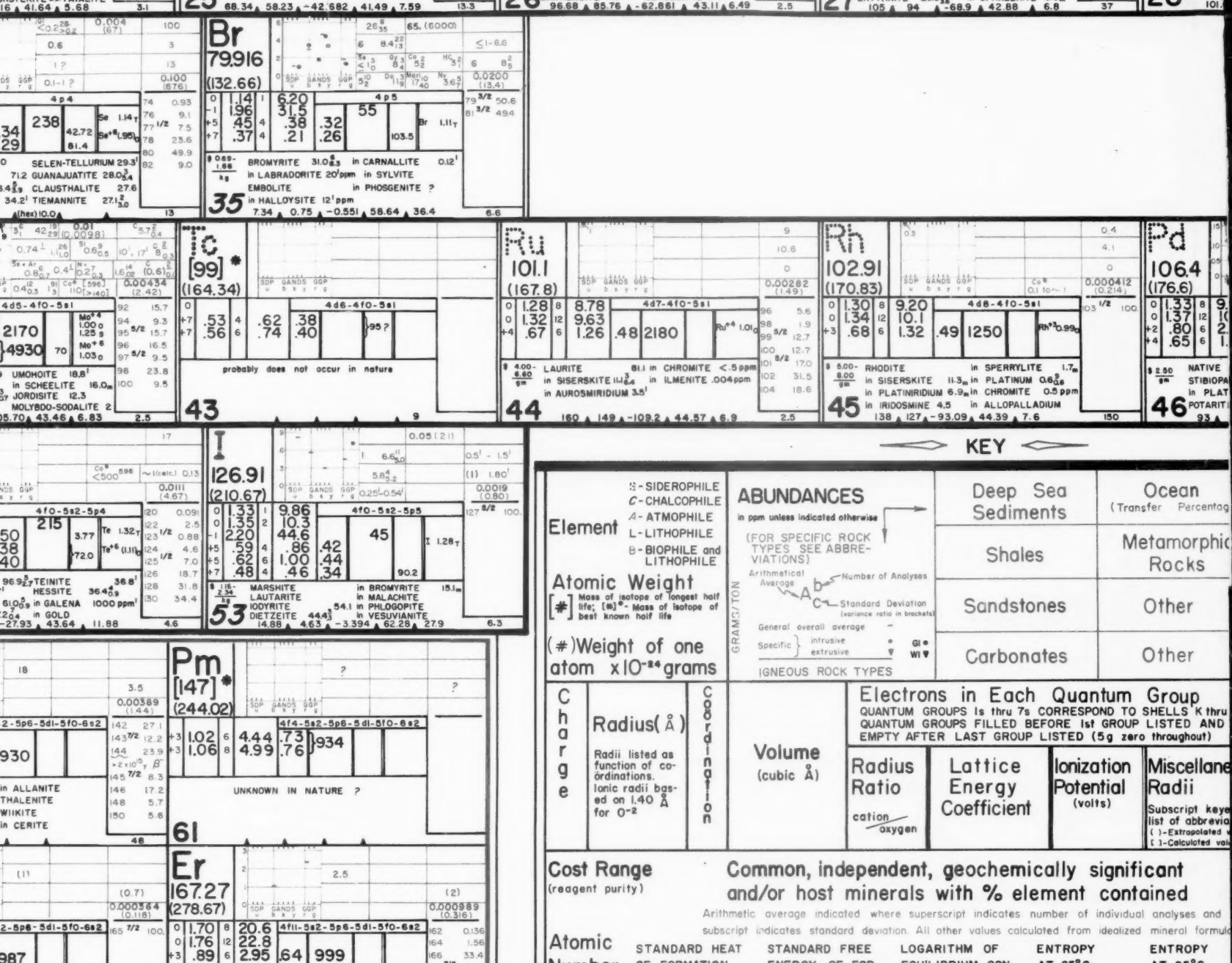








GEOCHEMICAL TABLE OF THE



KEY

Element
S - SIDEROPHILE
C - CHALCOPHILE
A - ATMOPHILE
L - LITHOPHILE
B - BIOPHILE and LITHOPHILE

Atomic Weight
[#] Mass of isotope of longest half life; [*] - Mass of isotope of best known half life

(#) Weight of one atom x 10^{-24} grams

ABUNDANCES
in ppm unless indicated otherwise
(FOR SPECIFIC ROCK TYPES SEE ABBREVIATIONS)
GRAMS/TON
Arithmetical Average A, a, b, c — Number of Analyses; Standard Deviation (variance ratio in brackets)
General overall average
Specific: intrusive ●, extrusive ▼ — GI ●, WI ▼
IGNEOUS ROCK TYPES

Deep Sea Sediments	Ocean (Transfer Percentag
Shales	Metamorphic Rocks
Sandstones	Other
Carbonates	Other

Charge | Radius (Å) — Radii listed as function of coordinations. Ionic radii based on 1.40 Å for O^{-2} | Coordination

Volume (cubic Å)

Electrons in Each Quantum Group
QUANTUM GROUPS 1s thru 7s CORRESPOND TO SHELLS K thru
QUANTUM GROUPS FILLED BEFORE 1st GROUP LISTED AND EMPTY AFTER LAST GROUP LISTED (5g zero throughout)

Radius Ratio (cation/oxygen) | Lattice Energy Coefficient | Ionization Potential (volts) | Miscellane Radii — Subscript keye list of abbrevia ( )-Extrapolated [ ]-Calculated vol

Cost Range (reagent purity)

Common, independent, geochemically significant and/or host minerals with % element contained

Arithmetic average indicated where superscript indicates number of individual analyses and subscript indicates standard deviation. All other values calculated from idealized mineral formula

Atomic Number (slanted for "dispersed" elements)	STANDARD HEAT OF FORMATION ΔHf° (GAS) kg-cal/mole	STANDARD FREE ENERGY OF FORMATION ΔFf° (GAS) kg-cal/mole	LOGARITHM OF EQUILIBRIUM CONSTANT OF FORMATION (25° C) log Kf (GAS)	ENTROPY AT 25°C S° (GAS) cal/degree-mole	ENTROPY AT 25°C S° (SOLID) cal/degree-mo

KEY

Element
S - SIDEROPHILE
C - CHALCOPHILE
A - ATMOPHILE
L - LITHOPHILE
B - BIOPHILE and LITHOPHILE

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[#] Mass of isotope of longest half life; [#]* - Mass of isotope of best known half life

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ABUNDANCES
in ppm unless indicated otherwise
(FOR SPECIFIC ROCK TYPES SEE ABBREVIATIONS)
GRAMCITON
Arithmetical Average — A b c — Number of Analyses; Standard Deviation (variance ratio in brackets)
General overall average –
Specific: intrusive •, extrusive ▼; GI •, WI ▼
IGNEOUS ROCK TYPES

Deep Sea Sediments	Ocean (Transfer Percentage)	Meteoritic Sulfides (C = sulfide phase of chondrites)
Shales	Metamorphic Rocks	Meteoritic Irons (C = iron phase of chondrites)
Sandstones	Other	Chondrites (C = silicate phase of chondrites)
Carbonates	Other	Universe including volatiles (Atoms per 10^6 Si Atoms)

Charge | Radius (Å) — Radii listed as function of coordinations. Ionic radii based on 1.40 Å for O^{-2} | Coordination | Volume (cubic Å)

Electrons in Each Quantum Group
QUANTUM GROUPS 1s thru 7s CORRESPOND TO SHELLS K thru Q; QUANTUM GROUPS FILLED BEFORE 1st GROUP LISTED AND EMPTY AFTER LAST GROUP LISTED (5g zero throughout)

Radius Ratio (cation / oxygen) | Lattice Energy Coefficient | Ionization Potential (volts) | Miscellaneous Radii — Subscript keyed to list of abbreviations; ( )-Extrapolated value; [ ]-Calculated value

Naturally Occurring Isotopes
$A^{\#}$ % Relative Abundance
Nuclear spin in multiples of $h/2\pi$ indicated by superscript.

RADIOACTIVE ISOTOPE ~~~ HALF-LIFE — RADIATION DECAY
d - Days; h - Hours; m - Minutes; s - Seconds; y - Years
α - Alpha particle decay; β⁻ - Negative beta decay
γ - Gamma ray (subsequent radiation)
e⁻ - Prominent internal conversion electron
IT - Isomeric transition
K - K electron capture
L - L electron capture

Cost Range (reagent purity)

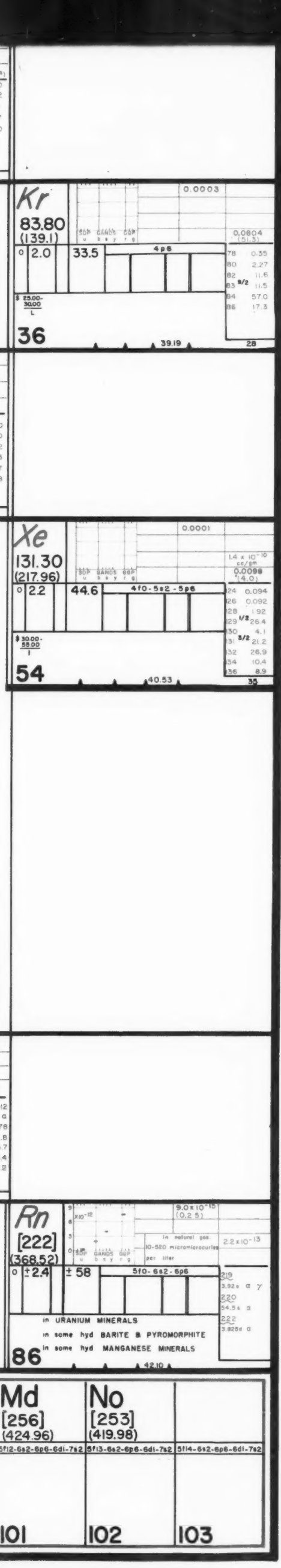
Common, independent, geochemically significant and/or host minerals with % element contained

Arithmetic average indicated where superscript indicates number of individual analyses and subscript indicates standard deviation. All other values calculated from idealized mineral formula.

Atomic Number (slanted for "dispersed" elements)

STANDARD HEAT OF FORMATION ΔHf° (GAS)	STANDARD FREE ENERGY OF FORMATION ΔFf° (GAS)	LOGARITHM OF EQUILIBRIUM CONSTANT OF FORMATION (25° C)	ENTROPY AT 25°C S° (GAS)	ENTROPY AT 25°C S° (SOLID)
kg-cal/mole	kg-cal/mole	log Kf (GAS)	cal/degree-mole	cal/degree-mole

Thermal neutron absorption cross section in barns



$H_2O_2 + 2H^{+1} + 2e_0^- \rightleftharpoons 2H_2O$	1.77
$Co^{+3} + e_0^- \rightleftharpoons Co^{+2}$	1.842 ± 0.001

ELECTROCHEMICAL EQUIVALENTS

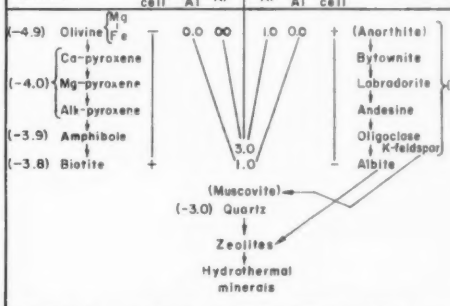
(Milligrams per Coulomb)

H^{+1}	0.010446	Po^{+6}	0.36269
D_2^{+1}	0.020878	Cl^{-1}	0.36743
N^{+5}	0.029032	Ta^{+5}	0.37488
C^{+4}	0.031113	In^{+3}	0.39641
B^{+3}	0.03737	K^{+1}	0.40514
He^{+0}	0.04147	U^{+6}	0.41117
Be^{+2}	0.04674	A^{+0}	0.41393
N^{+3}	0.048387	Sb^{+3}	0.42059
S^{+6}	0.05537	Bi^{+5}	0.43316
C^{+2}	0.06223	Sr^{+2}	0.45404
P^{+5}	0.06421	Hf^{+4}	0.46269
Li^{+1}	0.07192	La^{+3}	0.47986
Si^{+4}	0.07269	Ce^{+3}	0.48404
O^{-2}	0.082902	Pr^{+3}	0.48677
S^{+4}	0.08306	Os^{+4}	0.49611
Cr^{+6}	0.08983	Nd^{+3}	0.49834
Al^{+3}	0.09316	Ir^{+4}	0.50026
V^{+5}	0.10560	Pm^{+3}	0.50432
Ti^{+4}	0.12409	Pt^{+4}	0.50578
Mg^{+2}	0.12601	Sm^{+3}	0.51962
Se^{+6}	0.13637	Eu^{+3}	0.52504
Mn^{+4}	0.14230	Pb^{+4}	0.53681
Tc^{+7}	0.14478	Gd^{+3}	0.54179
As^{+5}	0.15254	Tb^{+3}	0.54991
Sc^{+3}	0.15579	Dy^{+3}	0.56069
Mo^{+6}	0.16580	Ho^{+3}	0.56974
S^{-2}	0.16611	Er^{+3}	0.57907
Cr^{+3}	0.17965	Cd^{+2}	0.58244
Ge^{+4}	0.18808	Tm^{+3}	0.58515
Nb^{+5}	0.19256	Yb^{+3}	0.59772
Fe^{+3}	0.19291	Pa^{+5}	0.59845
F^{-1}	0.19689	Th^{+4}	0.60135
Ca^{+2}	0.20767	Lu^{+3}	0.60446
Ne^{+0}	0.20915	Sn^{+2}	0.61503
Te^{+6}	0.22040	Cu^{+1}	0.65876
Zr^{+4}	0.23632	Au^{+3}	0.68117
Na^{+1}	0.23831	Tl^{+3}	0.70601
Ga^{+3}	0.24083	Ba^{+2}	0.71171
Sb^{+5}	0.25235	Bi^{+3}	0.72193
As^{+3}	0.25876	Ac^{+3}	0.78411
Ru^{+4}	0.26347	Br^{+1}	0.82815
Rh^{+4}	0.26661	Kr^{+0}	0.86736
Re^{+7}	0.27581	Rb^{+1}	0.88580
Pd^{+4}	0.27642	Hg^{+2}	1.03943
Mn^{+2}	0.28461	Pb^{+2}	1.07363
Fe^{+2}	0.28938	Ag^{+1}	1.11793
Ni^{+2}	0.30409	Ra^{+2}	1.17124
Co^{+2}	0.30539	I^{-1}	1.31523
Y^{+3}	0.30715	Xe^{+0}	1.36062
Sn^{+4}	0.30751	Cs^{+1}	1.37731
W^{+6}	0.31779	Au^{+1}	2.04352
Cu^{+2}	0.32938	Hg^{+1}	2.07886
Zn^{+2}	0.33876	Rn^{+0}	2.30052

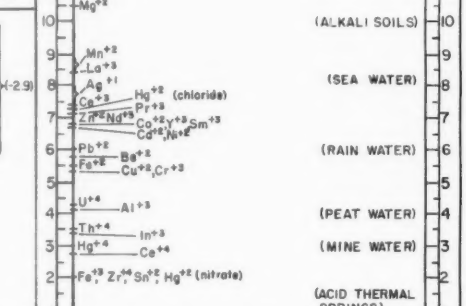
SEQUENCE OF CATIONS ACCORDING TO FIELD STRENGTH

ELEMENT	COORD NO.	FIELD STRENGTH	ELEMENT	COORD NO.	FIELD STRENGTH
K^{+1}	8	0.13	Zr^{+4}	8	0.77
Na^{+1}	6	0.19	Be^{+2}	4	0.86
Li^{+1}	6	0.23	Fe^{+3}	6	0.76
Ba^{+2}	8	0.245		4	0.85
Pb^{+2}	8	0.27	Al^{+3}	6	0.84
Sr^{+2}	8	0.28		4	0.96
Ca^{+2}	8	0.33	Ti^{+4}	6	1.04
Mn^{+2}	6	0.40	B^{+3}	4	1.34
Fe^{+2}	6	0.43		3	1.63
Zn^{+2}	4	0.49	Si^{+4}	4	1.57
Mg^{+2}	6	0.45	P^{+5}	4	2.1
	4	0.53			

DISCONTINUOUS REACTION SERIES



CONTINUOUS REACTION SERIES



Numbers in parentheses are relative lattice energies.

IONIC RADII

(Å)

Tl^{+1}	.03	Cu^{+2}	.14	Al^{+3} (6 FOLD COORD.)	.23
K^{+1}	.03	Co^{+2}	.14	Be^{+2}	.24
Ag^{+1}	.04	Sn^{+2}	.14	Hf^{+4}	.27
Na^{+1}	.06	Ni^{+2}	.14	Nb^{+4}	.28
Cu^{+1}	.06	Mg^{+2}	.14	W^{+4}	.28
Ba^{+2}	.07	Th^{+4}	.16	Mo^{+4}	.28
Pb^{+2}	.08	U^{+4}	.19	Ti^{+4}	.28
Sr^{+2}	.08	Zr^{+4}	.20	Al^{+3} (4 FOLD COORD.)	.35
Ca^{+2}	.09	Sc^{+3}	.20	Bi^{+5}	.35
Cd^{+2}	.09	In^{+3}	.20		.39
Li^{+1}	.10	V^{+3}	.21	Ge^{+4}	.46
La^{+3}	.12	Mn^{+3}	.21	Si^{+4}	.48
Mn^{+2}	.13	Fe^{+3}	.22	As^{+5}	.60
Y^{+3}	.14	Cr^{+3}	.22	P^{+5}	.62

ENTROPIES S_0 OF IONS IN AQUEOUS SOLUTION AT 25°C.

(In cal. degree^{-1}.mol^{-1})
with reference to $S_{0,H^{+1}} = 0$

MnO_4^{-1}	46.7 ± 0.4	Sn^{+2}	−4.9 ± 1.0
Cs^{+1}	31.8 ± 0.6	Sr^{+2}	−7.3 ± 1.5
Mg^{+2}	31.6 ± 3	Ca^{+2}	−12.7 ± 0.6
Tl^{+1}	30.5 ± 0.4	CO_3^{-2}	−13.0 ± 1.0
NO_3^{-1}	29.9 ± 1	Cd^{+2}	−16.4 ± 1.5
Rb^{+1}	28.7 ± 0.7	Mn^{+2}	−19.1
IO_3^{-1}	28.0 ± 1.0	Zn^{+2}	−25.7 ± 1.0
NH_4^{+1}	26.6 ± 0.6	Fe^{+2}	−25.9 ± 1.0
I^{-1}	25.3	Cu^{+2}	−26 5 ± 1.0
CN^{-1}	25 ±5	Be^{+2}	−27
K^{+1}	24.2 ± 0.2	Co^{+2}	−27
HCO_3^{-1}	22.2 ± 0.8	Ni^{+2}	−31
$H_2PO_4^{-1}$	21.6 ± 0.3	Y^{+3}	−34
Br^{-1}	19.7	Tl^{+3}	−35
Hg_2^{+2}	19.7 ± 3	In^{+3}	−42
Ag^{+1}	17 54 ± 0.15	Sb^{+3}	−43
HS^{-1}	14.9 ± 1.0	Se^{+3}	−48
Na^{+1}	14.0 ± 0.4	PO_4^{-3}	−52 ± 2
Cl^{-1}	13.50	Mn^{+3}	−59
CrO_4^{-2}	10.6 ± 1.0	As^{+3}	−60
$C_2O_4^{-2}$	9.6 ± 1.0	Rh^{+3}	−60
HPO_4^{-2}	8.7 ± 1.0	Fe^{+3}	−61 ± 5
Li^{+1}	4.7 ± 1.0	V^{+3}	−65
SO_4^{-2}	4.4 ± 0.5	Th^{+4}	−65
Pb^{+2}	3.9 ± 0.9	Cr^{+3}	−65
SO_3^{-2}	3 ± 3	U^{+4}	−67.9
OH^{-1}	2.49 ± 0.06	Ga^{+3}	−69
F^{-1}	2.3 ± 2	Al^{+3}	−76 ±10
Ba^{+2}	2.3 ± 0.3	Te^{+4}	−79
H	0.00	Zr^{+4}	−81
		Pb^{+4}	−84
		Sn^{+4}	−95
		Nb^{+4}	−101
		W^{+4}	−103
		Mo^{+4}	−103
		Os^{+4}	−104
		Ir^{+4}	−106
		Ru^{+4}	−108
		Ti^{+4}	−109
		V^{+4}	−114
		Ge^{+4}	−157
		Si^{+4}	−177

SOLUBILITY OF SULFIDES

Hg
Ag
Cu
Bi
Cd
Pb
Zn
Ni
Co
Fe^{+2}
Mn

upper replaces lower

ZONING

Hg (232)
Sb Cd (163)
Pb (156)
Zn (142)
Cu (143)
Au
As
Te
Bi
Sn (130)
W Mo Ni (98)
Co (93) Mn (87)

Se
Ag

HEATED SOURCE

Numbers in parentheses are stability factors Fe (94) and S present throughout series

EXCHANGEABILITY

In clay minerals

Li^{+1}
Na^{+1}
NH_4^{+1}
K^{+1}
Mg^{+2}
Rb^{+1}
NH_4^{+1}
Ca^{+2}
Sr^{+2}
Ba^{+2}
Co^{+3}
Al^{+3}

lower replaces upper

AFFINITY FOR SULFUR IN MELT

increasing affinity

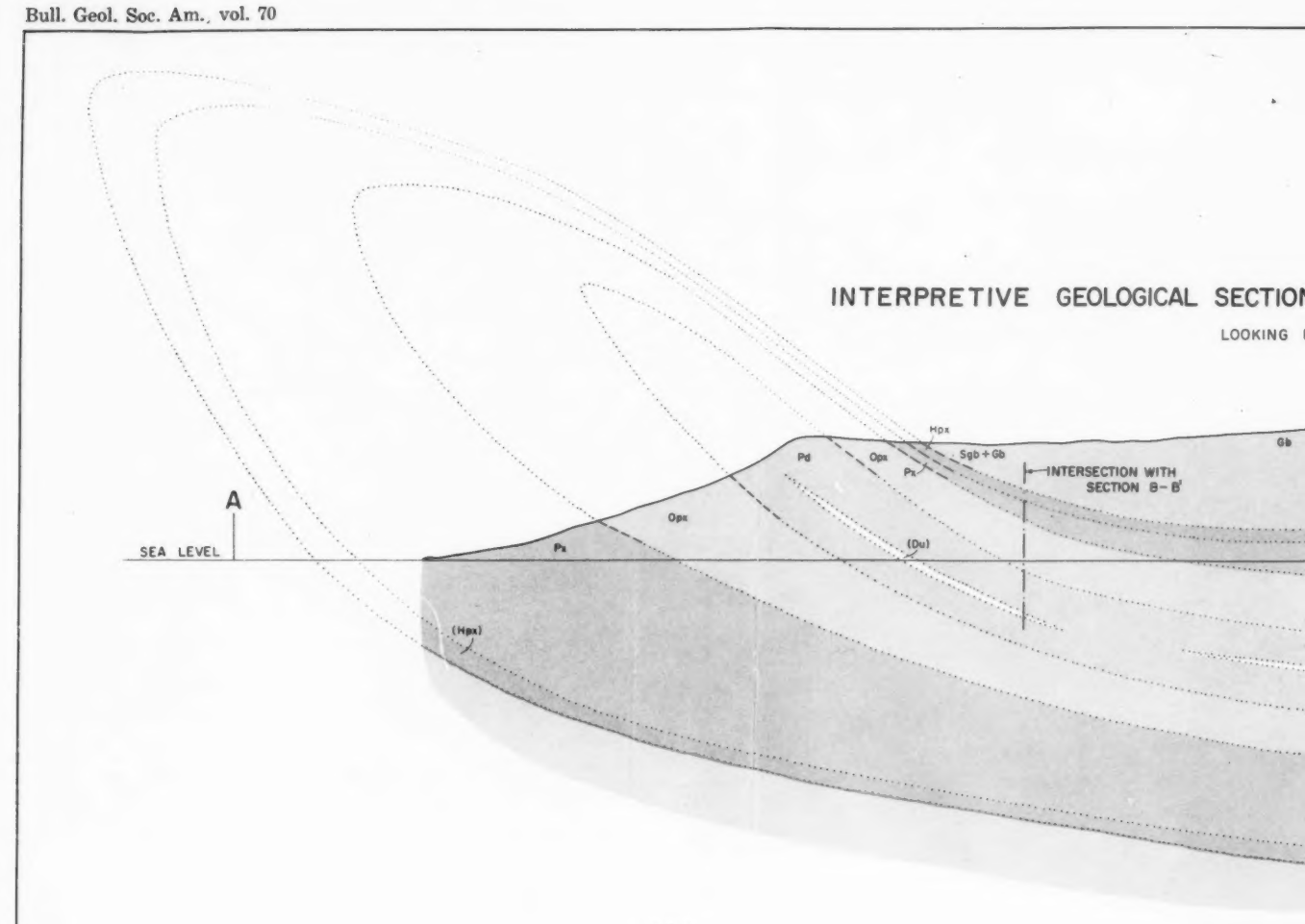
Mn
Cu
Ni
Co
Fe
Sn
Zn
Pb
Sb
Ag

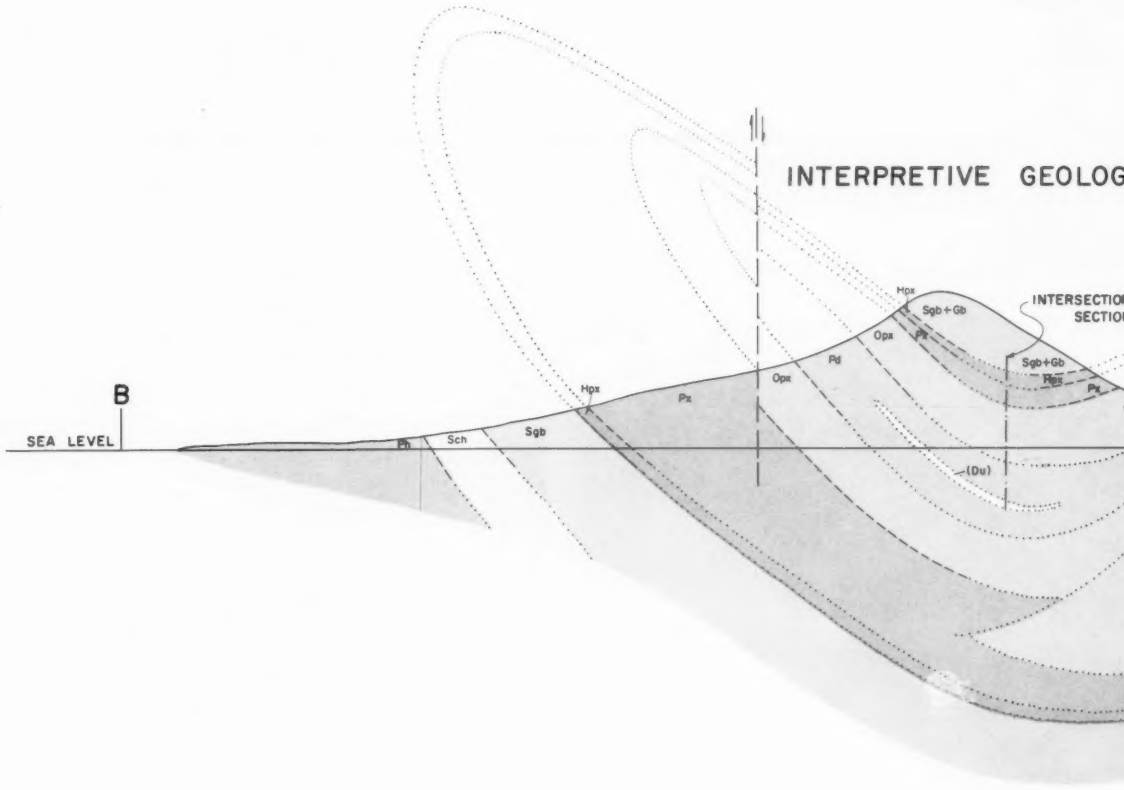
HYDROXIDE PRECIPITATION pH'S

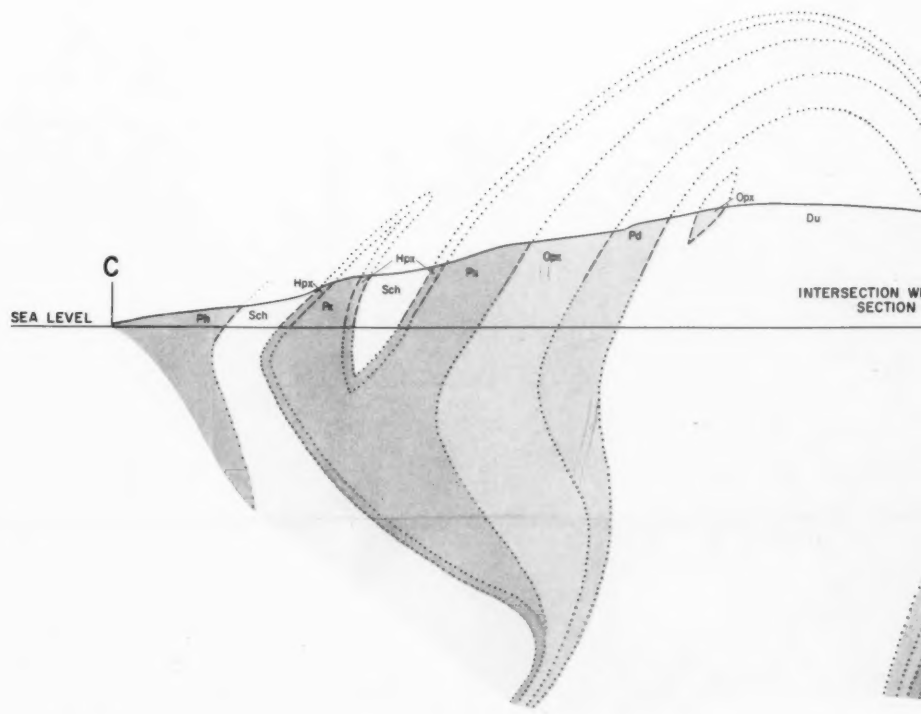
(From dilute solutions)

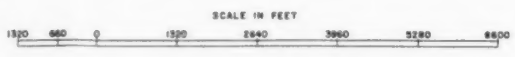
ABBREVIATIONS

A - anorthosite
Ac - achondrite
An - anhydrite and/or gypsum
Ap - aplite
Ar - arkose
B - bauxite
Bm - blue mud
C - chondrite
Co - coal
Co* - coal ash
D - diorite - andesite
Di - diatom ooze
Do - dolomite
Du - dunite
F - ionic radius in fluorides
f - Fersman lattice energy coefficient
G - granite - rhyolite
Gb - gabbro - basalt
Gl - globigerina ooze
Gn - gneiss
Gr - granodiorite - dacite
gr - gray
Gy - graywacke
Gs - greisen
H - hydrated radius
Ha - halite and/or rock salt
HC - crude oil
HC* - crude oil ash
hex - hexagonal
Hf - hornfels
hyd - hydrothermal
Ls - limestone
La - laterite
M - marble
m - maximum
ma - marine
mag - magmatic
N - norite
Nd - not detected
nm - non-marine
Ns - nepheline syenite - phonolite
Nv - novaculite and/or chert
O - radius in oxides
Ob - obsidian
org - organic
P - peridotite - limbergite
Pg - pegmatite
Po - porphyry
Pr - present
Q - quartzite
R - red clay
rhb - rhombohedral
S - sulfide or radius in sulfides
Sc - schist
sed - sediment
Sh - shale
Sl - slate
Ss - sandstone
Sy - syenite - trachyte
T - tetrahedral radius
ter - terrestrial
Tr - trace
WT - welded tuff







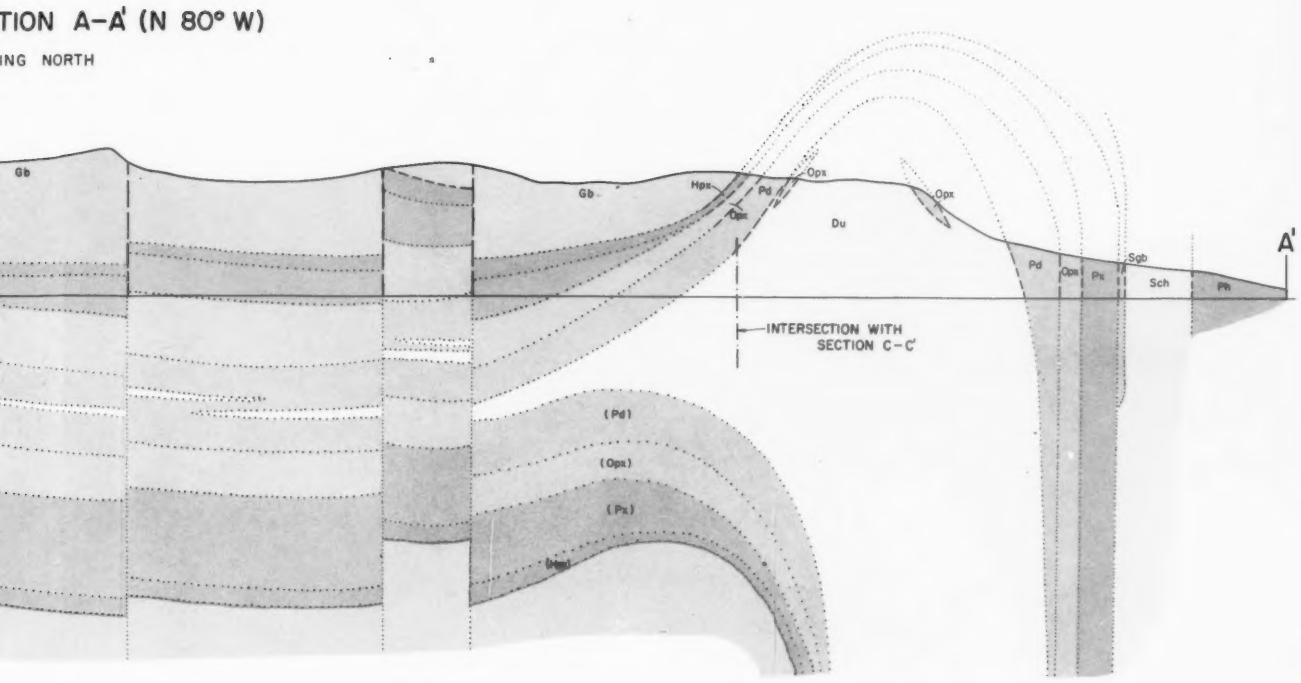


INTERPRETIVE GEOLOGICAL SECTIONS OF U

See Plate 1 for locat

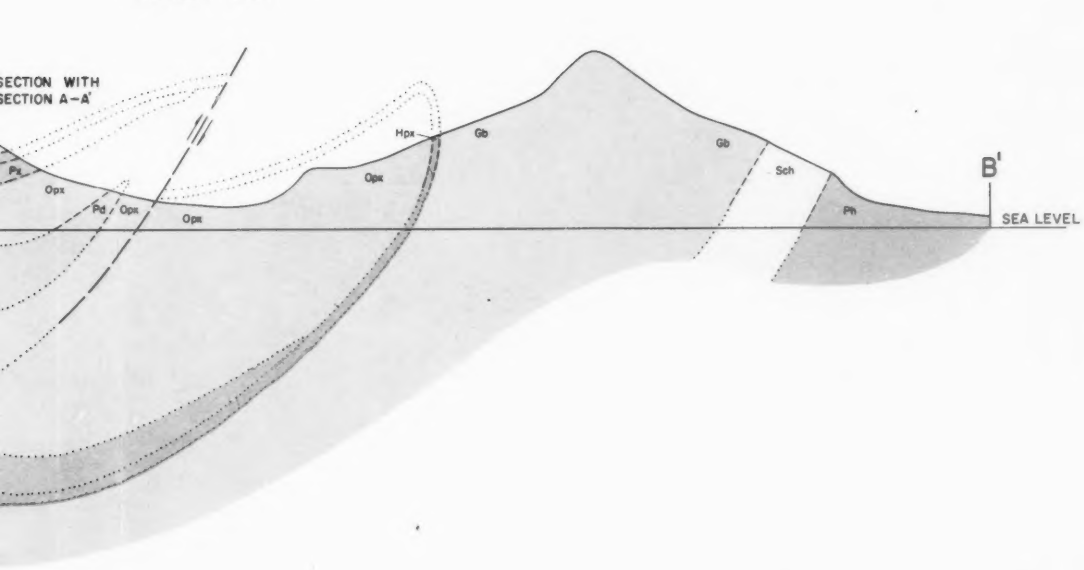
TION A–A' (N 80° W)

ING NORTH



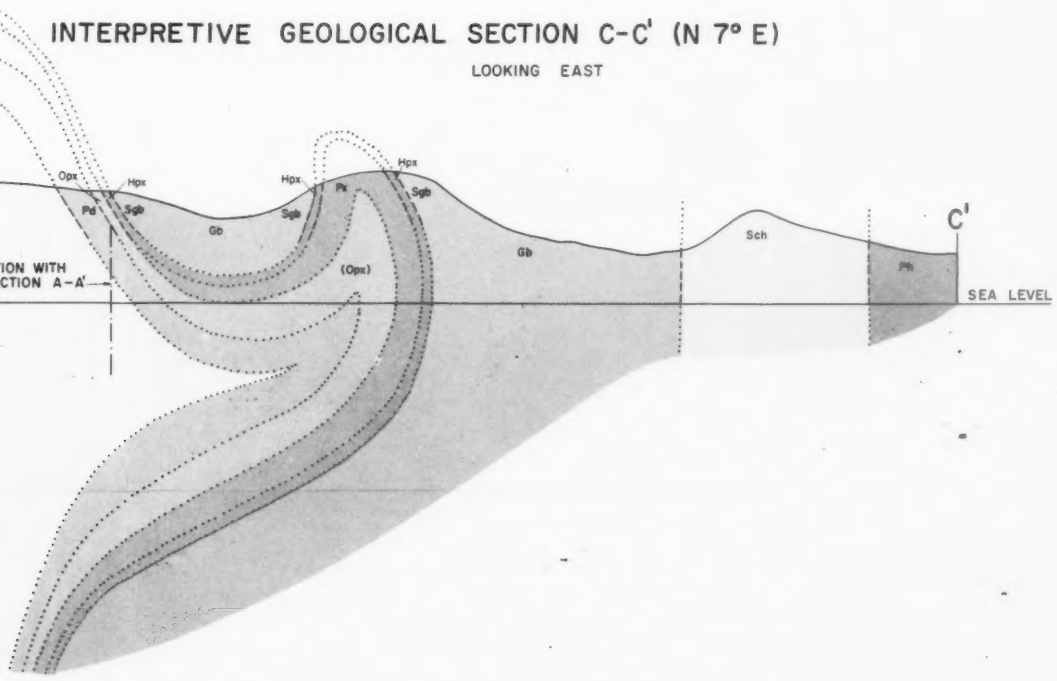
LOGICAL SECTION B–B' (N–S)

LOOKING EAST



INTERPRETIVE GEOLOGICAL SECTION C–C' (N 7° E)

LOOKING EAST

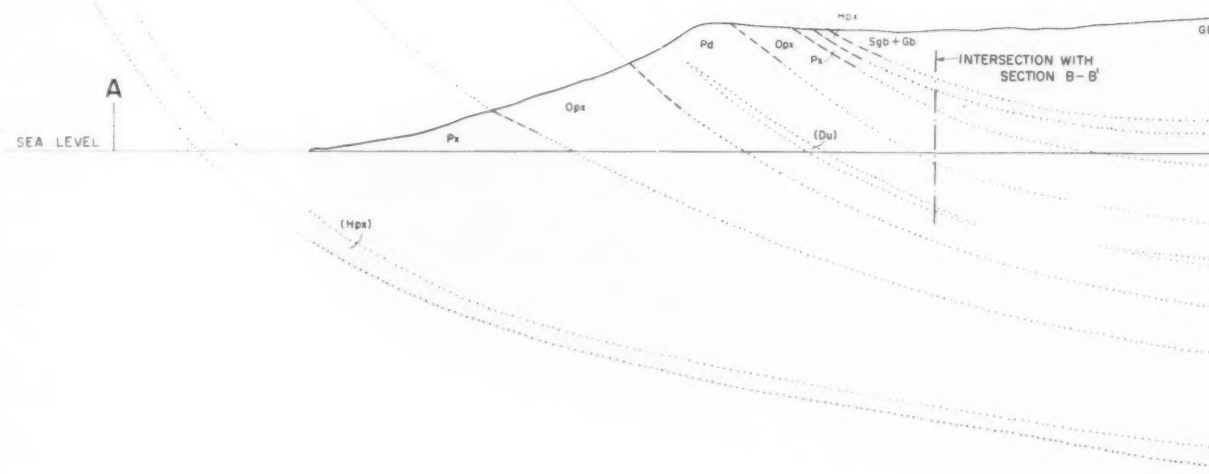


UNION BAY AREA, SOUTHEASTERN ALASKA

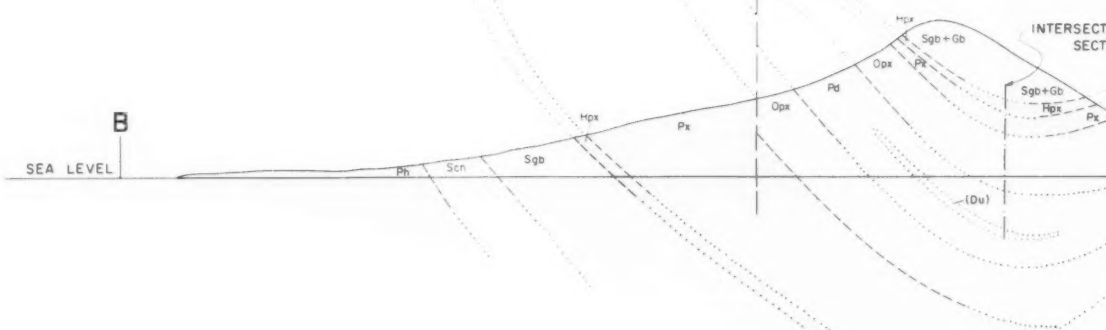
location and legend.

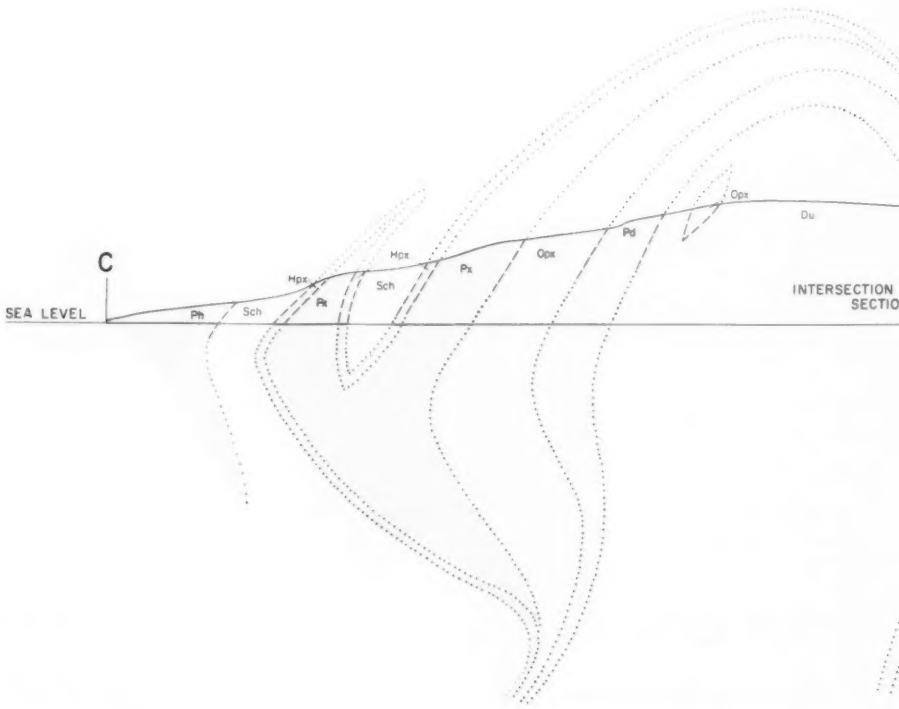
INTERPRETIVE GEOLOGICAL SECTIO

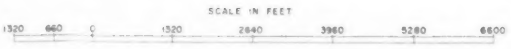
LOOKING



INTERPRETIVE GEOLO





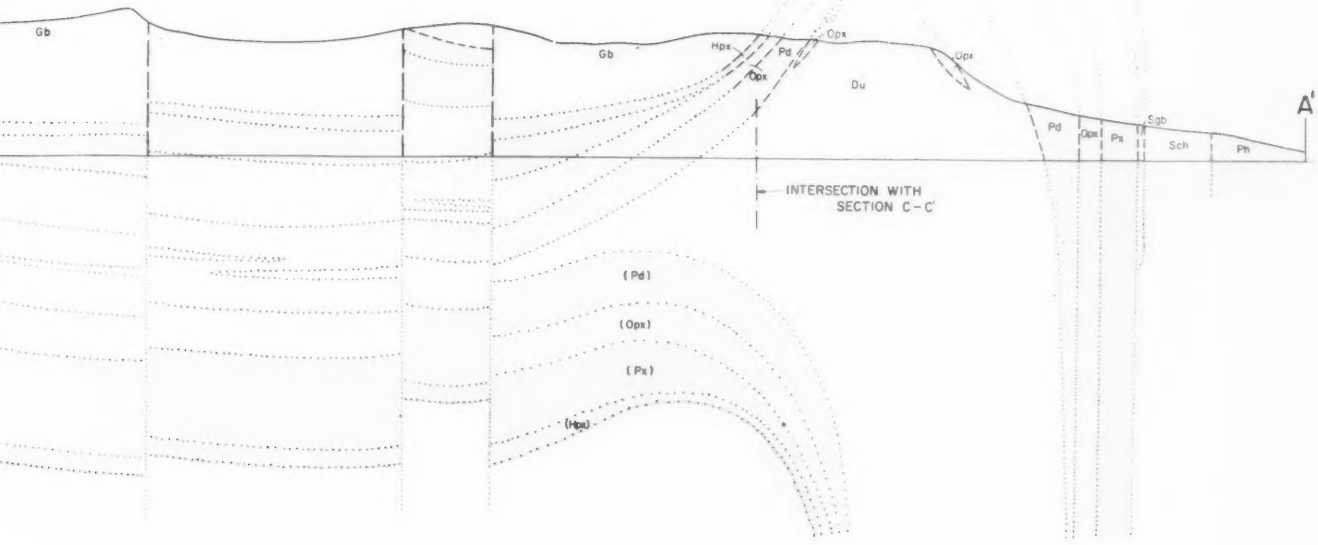


INTERPRETIVE GEOLOGICAL SECTIONS OF U

See Plate 1 for loc

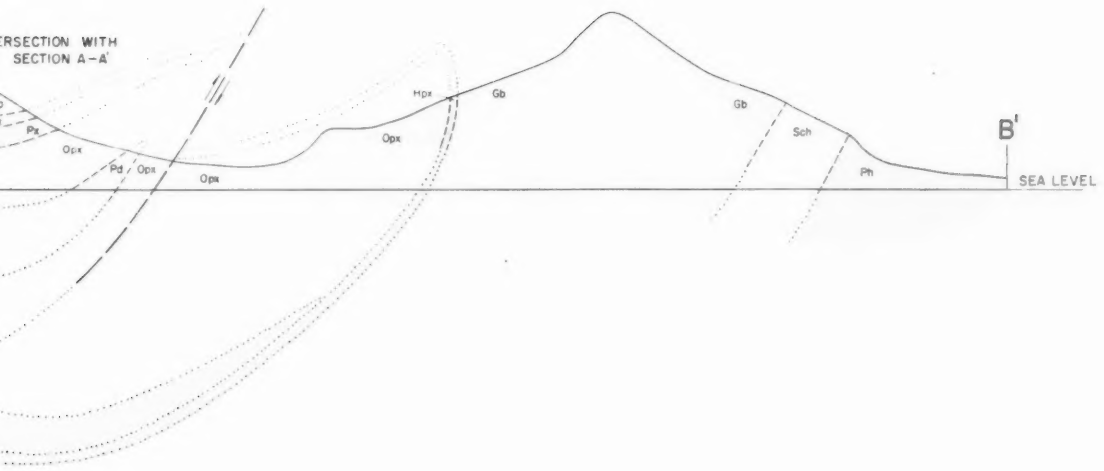
CTION A–A' (N 80° W)

OKING NORTH



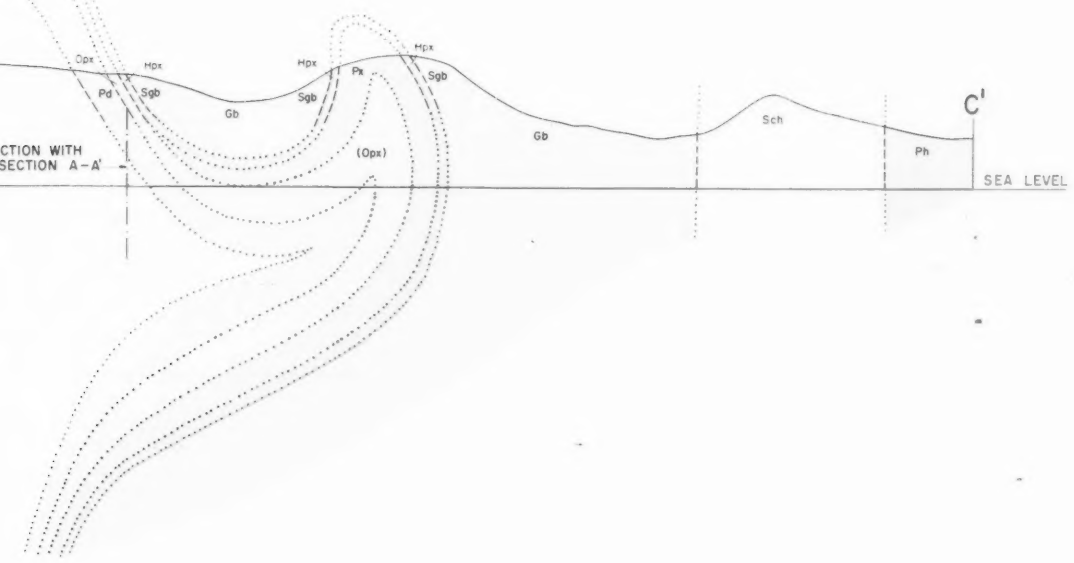
OLOGICAL SECTION B–B' (N–S)

LOOKING EAST



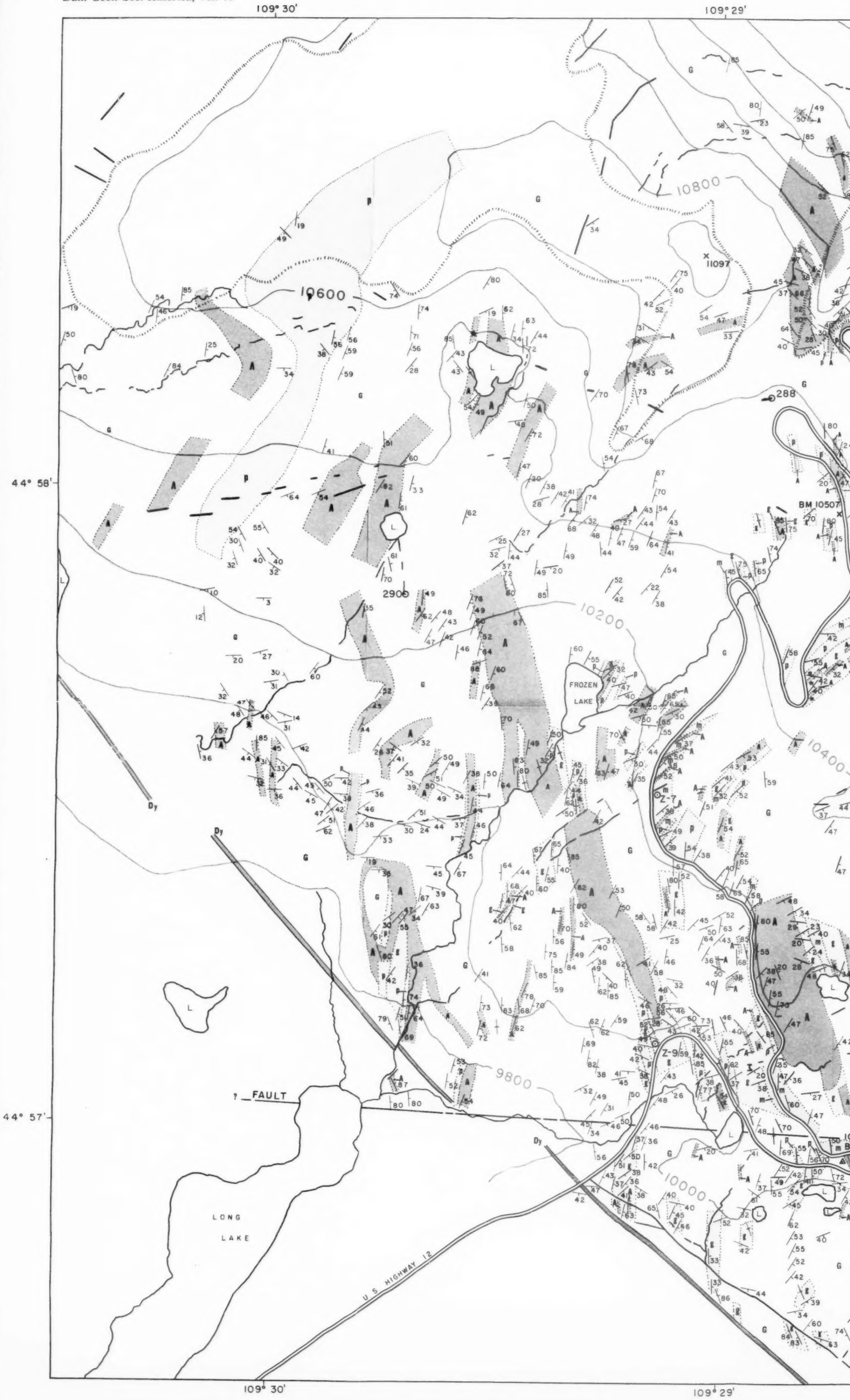
INTERPRETIVE GEOLOGICAL SECTION C–C' (N 7° E)

LOOKING EAST



F UNION BAY AREA, SOUTHEASTERN ALASKA

r location and legend.


109° 30'
109° 29'
44° 58'
44° 57'
10800
10600
10400
10200
10000
9800
2900
11097
288
BM 10507
FROZEN LAKE
LONG LAKE
? FAULT
U.S. HIGHWAY 12
Z-7
Z-9
Dy

109° 28'

109° 27'

9600

10000

10400

10800

11000

10200

9800

BM 10947
Beartooth Pass

BM 11029

BM 10536

SYNCLINAL AXIS

SYNCLINAL AXIS

FAULT

FAULT

FAULT

FAULT

GARDNER LAKE

BLACKSTONE LAKE

LOSEKAMP LAKE

10049 BM

Z-5

Z-6

149

153

1000 0

SYMBOLS

56 STRIKE AND DIP OF

SYNCLINAL AXIS

OBSERVED CONTACT

INFERRED CONTACT

HIGH-ANGLE FAUL

092 LOCATIONS OF CHE

SMALL LAKES AN

HIGHWAY, BENCH M

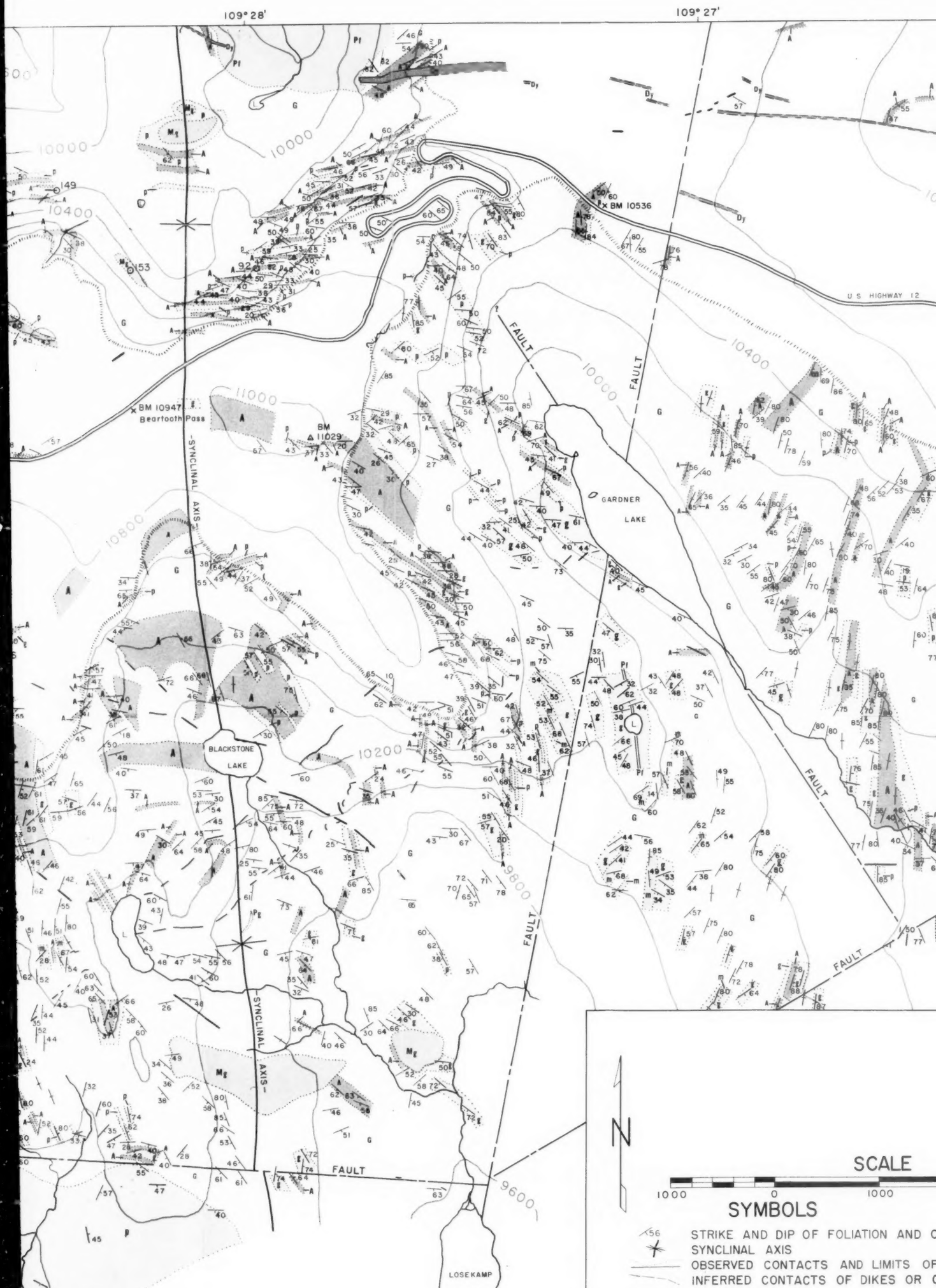
EDGE OF ESCARP

TOPOGRAPHIC CON

109° 28'

109° 27'

GEOLOGIC MAP OF THE GARDNER LAKE AREA, WYOMING



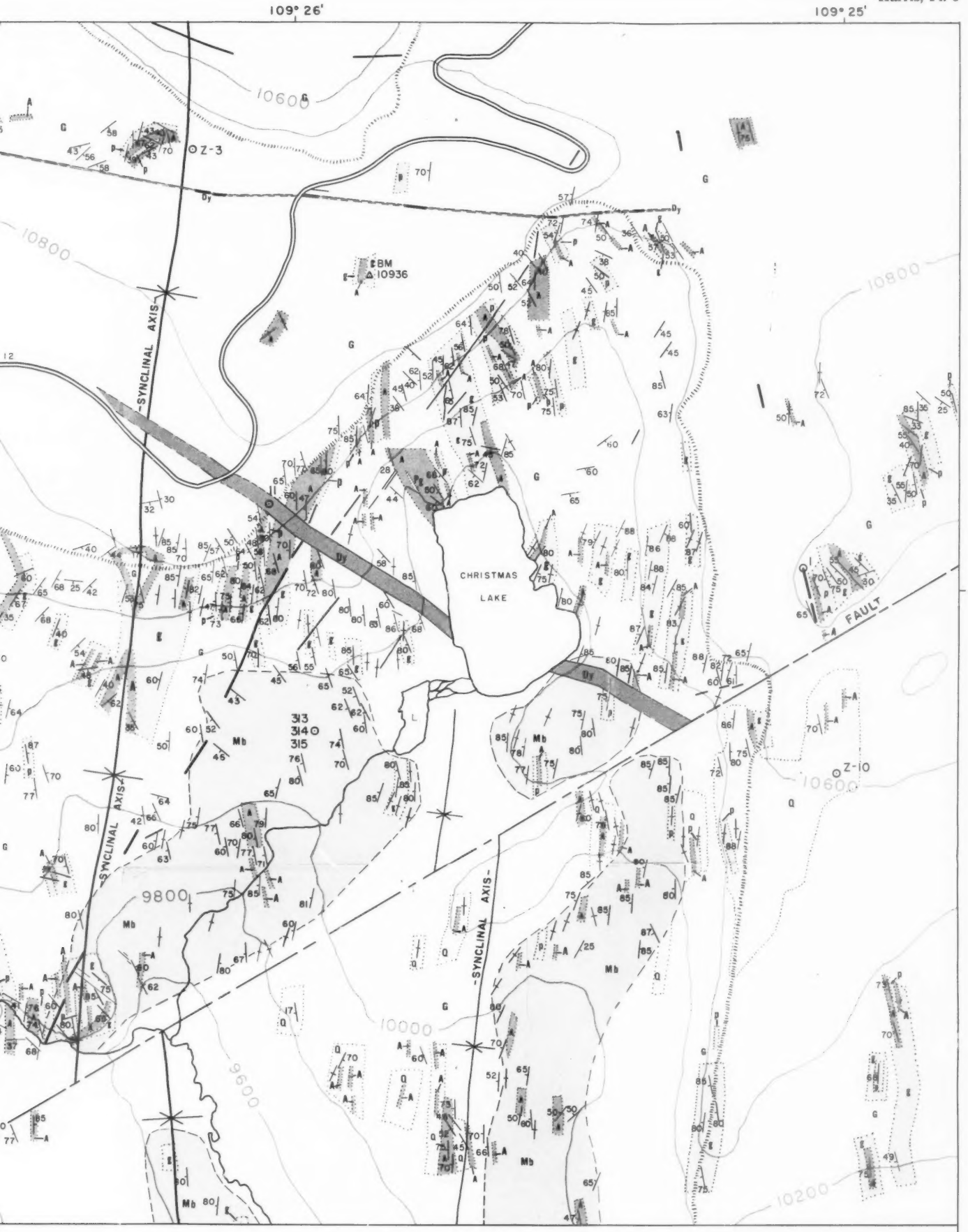
CEOLOGIC MAP OF THE GARDNER LAKE AREA, WYOMING

109° 26'

109° 25'

44° 58'

44° 57'



LEGEND

CRETACEOUS

- Pf — FELSIC PORPHYRY

PRECAMBRIAN

- Dy — YOUNGER PRECAMBRIAN DOLERITE DIKES
- ss — UNDIFFERENTIATED METAPICRITE AND METANORITE DIKES
- Mg — METAGABBRO
- Pg — PEGMATITES
- G — PINK LEUCOGRANITIC GNEISS AND AREA OF NO EXPOSURE
- g — GRAY GRANITIC GNEISS
- m — BIOTITE GNEISS WITH PINK MICROCLINE PORPHYROBLASTS
- p — BIOTITE GNEISS WITH WHITE PLAGIOCLASE PORPHYROBLASTS
- Mb — HIGHLY CONTORTED BANDED MIGMATITES
- A — FOLIATED AMPHIBOLITE
- Q — BANDED PLAGIOCLASE - QUARTZ GNEISS

2000 3000 FEET

ID OF ROCK UNITS

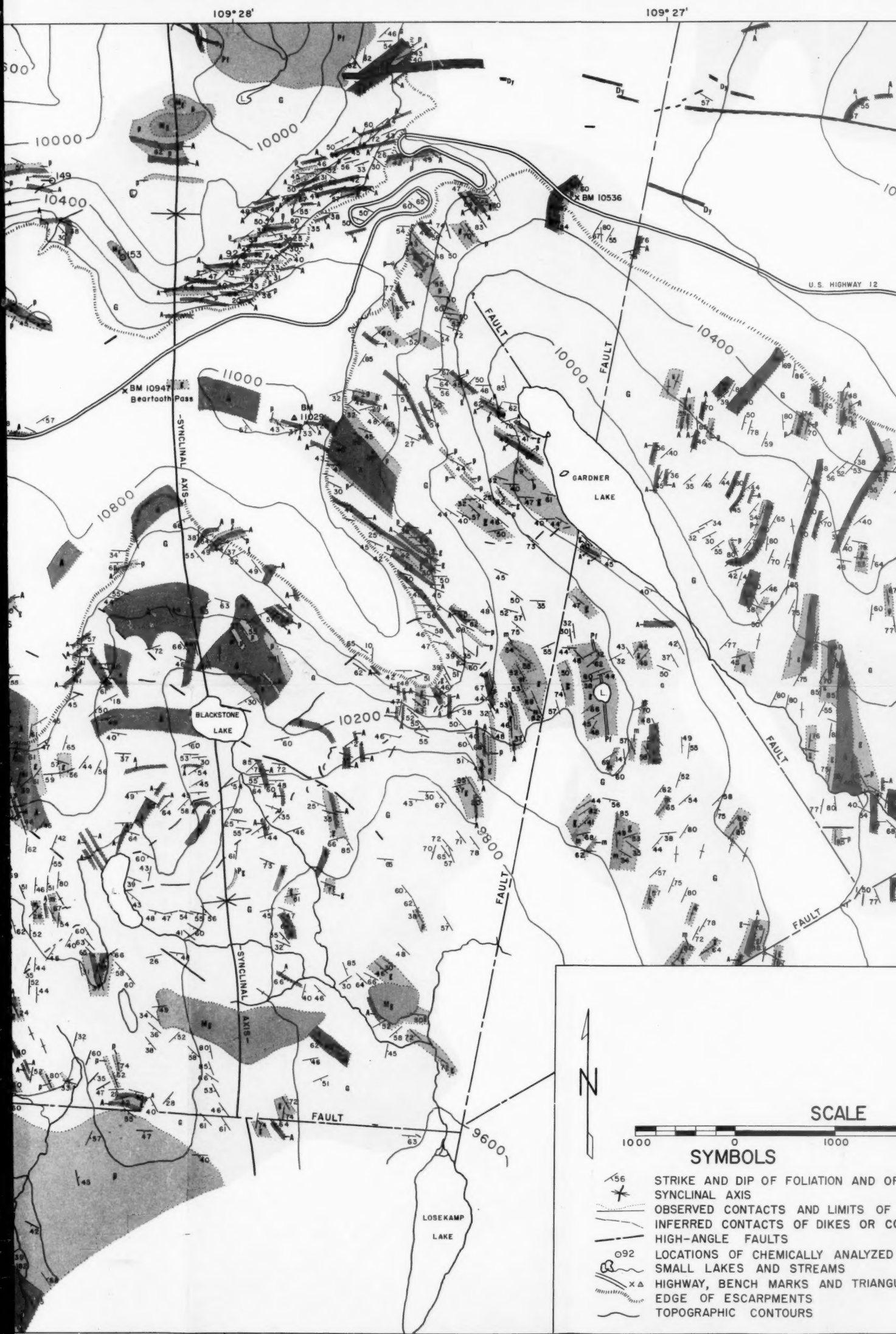
OF EXPOSURE
OR CONTORTED MIGMATITES

YZED SPECIMENS

IANGULATION STATIONS

109° 26'

109° 25'



109° 28' 109° 27'

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109° 26'

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10600

10800

10800

10000

9800

9600

10200

SYNCLINAL AXIS

SYNCLINAL AXIS

SYNCLINAL AXIS

BM 10936

Z-3

Z-10

CHRISTMAS LAKE

FAULT

313

314

315

Mb

L

Q

G

LEGEND

CRETACEOUS

- FELSIC PORPHYRY

PRECAMBRIAN

- YOUNGER PRECAMBRIAN DOLERITE DIKES
- UNDIFFERENTIATED METAPICRITE AND METANORITE DIKES
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2000 3000 FEET

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109° 26'

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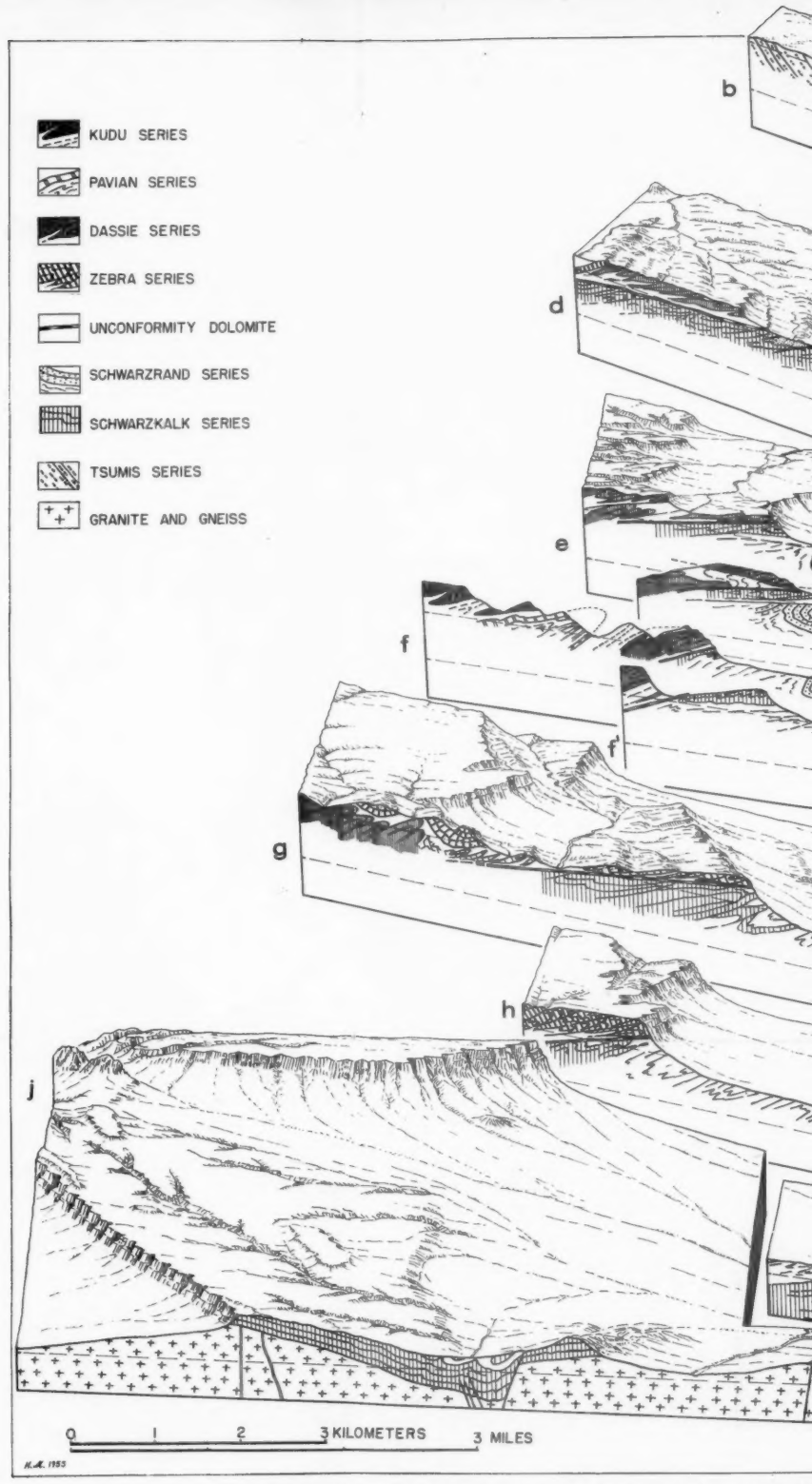
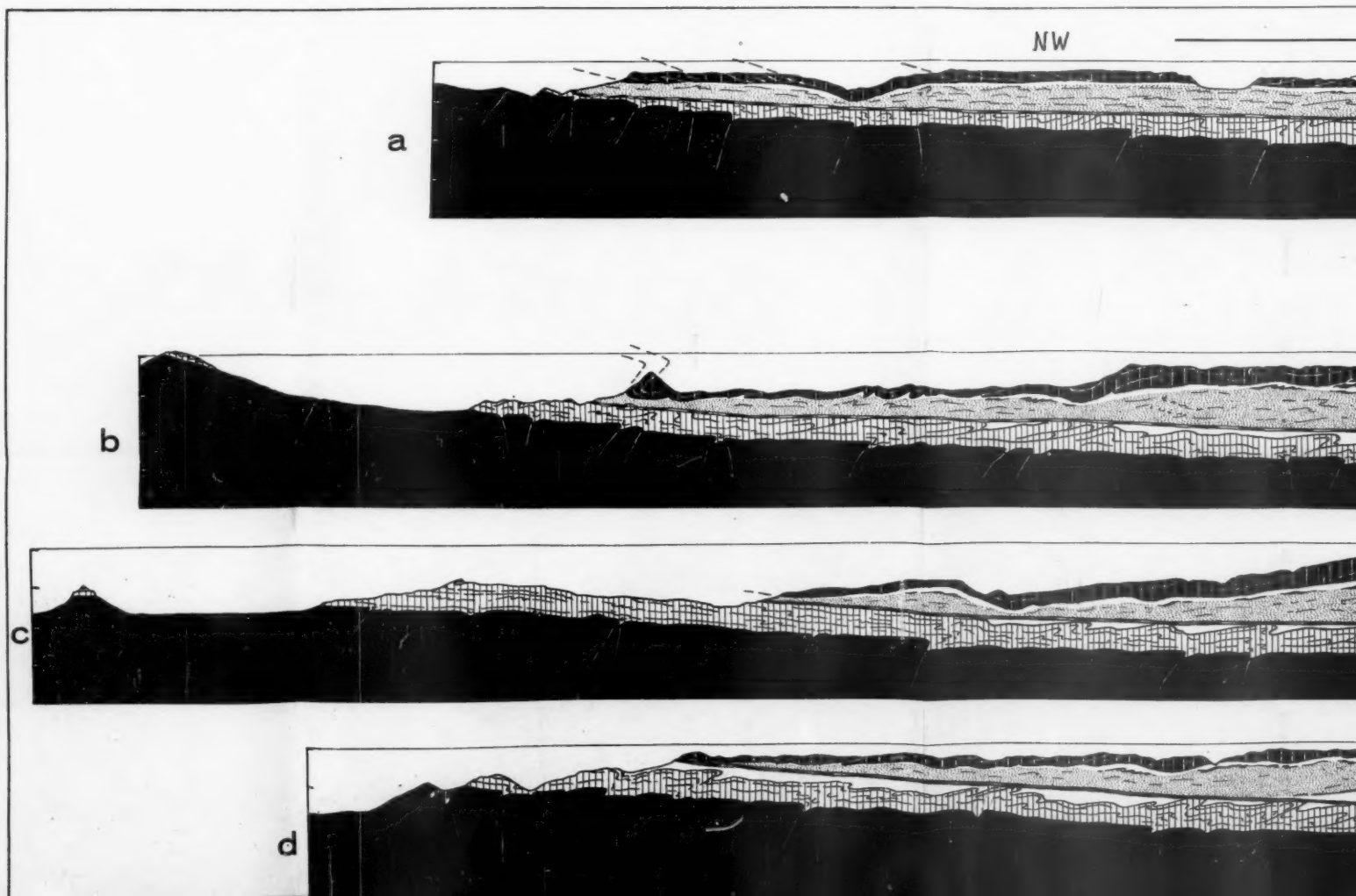
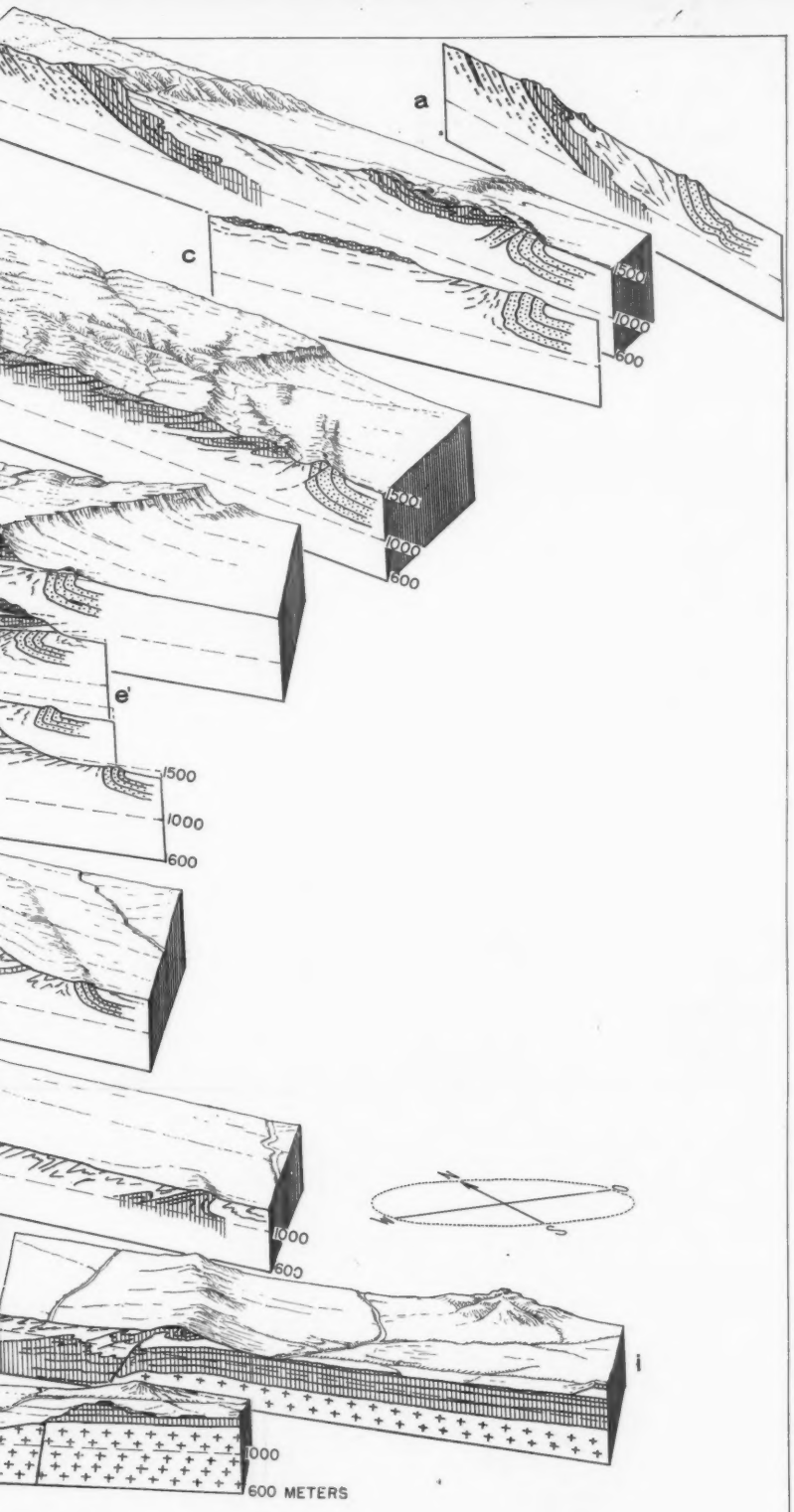


A. SECTIONS THROUGH SOUTHEASTERN

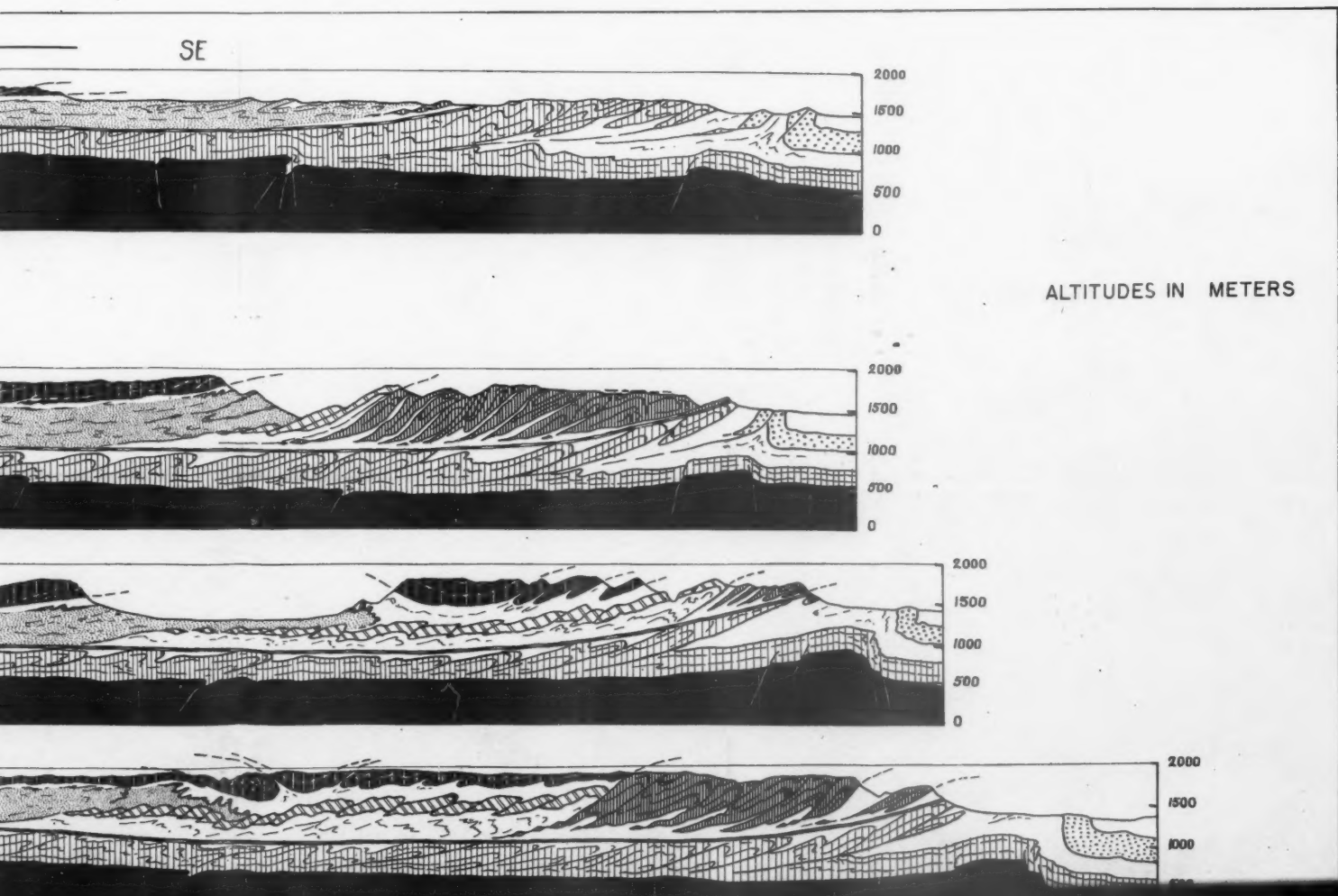
The profiles show the boundary between undeformed foreland and mountains. In the foreground are basement faults which may have determined the position of this boundary. In profiles *b*, *f*, and *g*, the Schwarzkalk beds of the mountains override, as a thrust sheet, the overturned younger

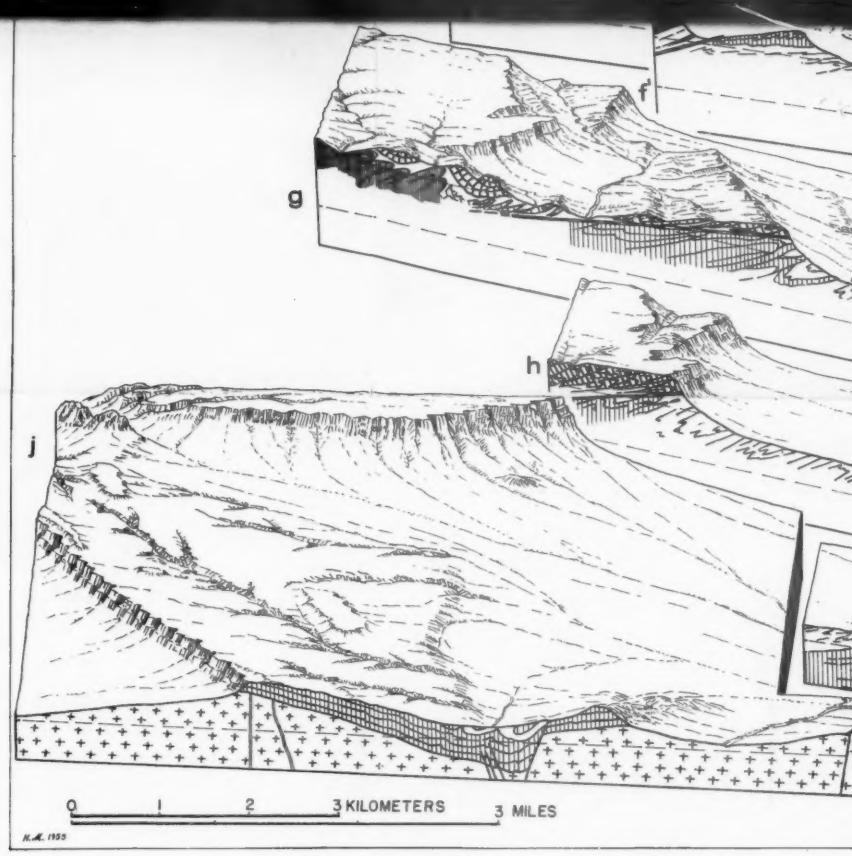




ERN FRONT OF NAUKLUFT MOUNTAINS

Schwarzrand beds of the foreland. Unconformity dolomite (checkered) truncates the folds in the Schwarzkalk thrusts. In profiles *g* and *h* it is overlain by the Zebra series, in the adjacent profiles by the Dassie nappe.





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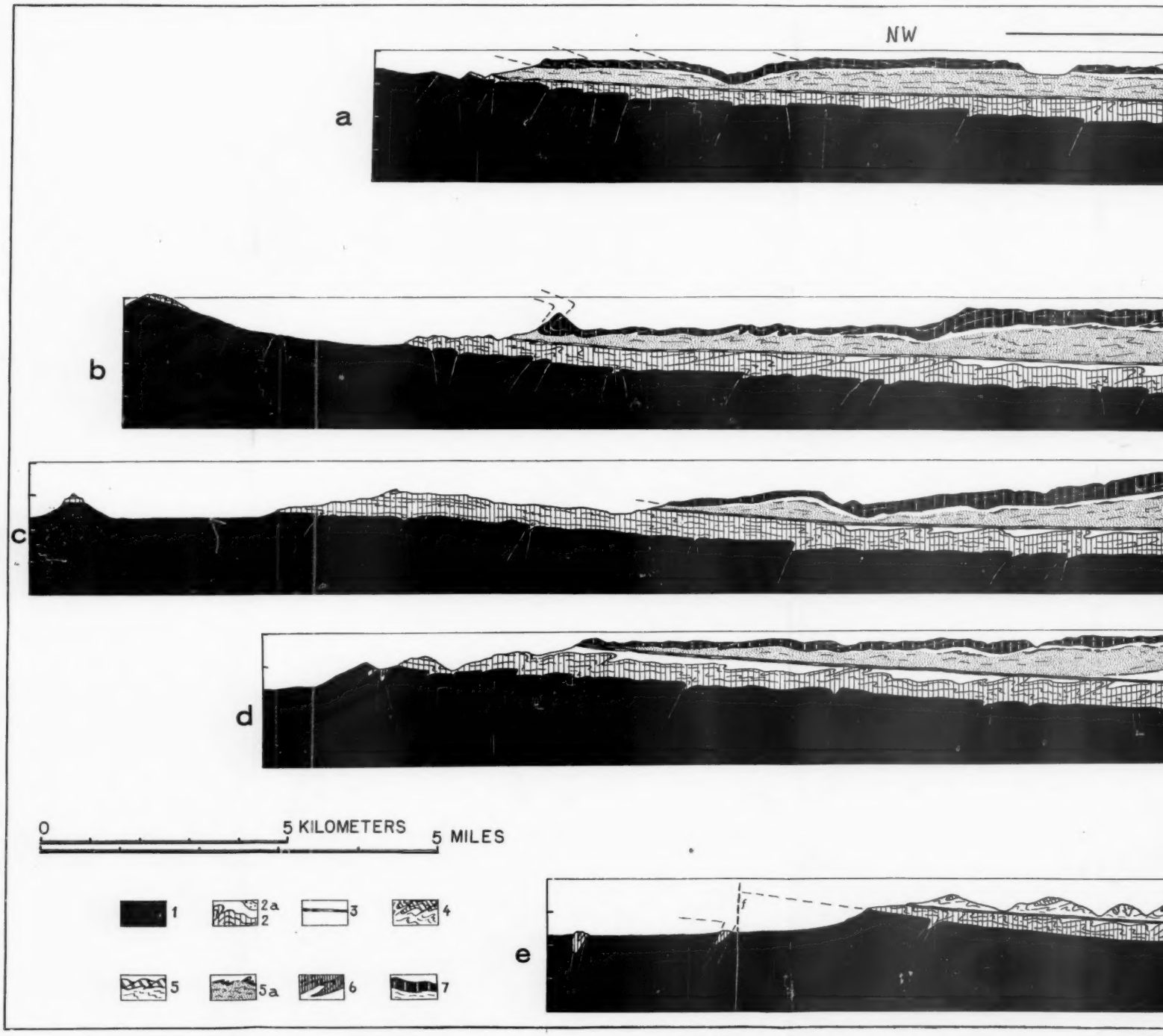
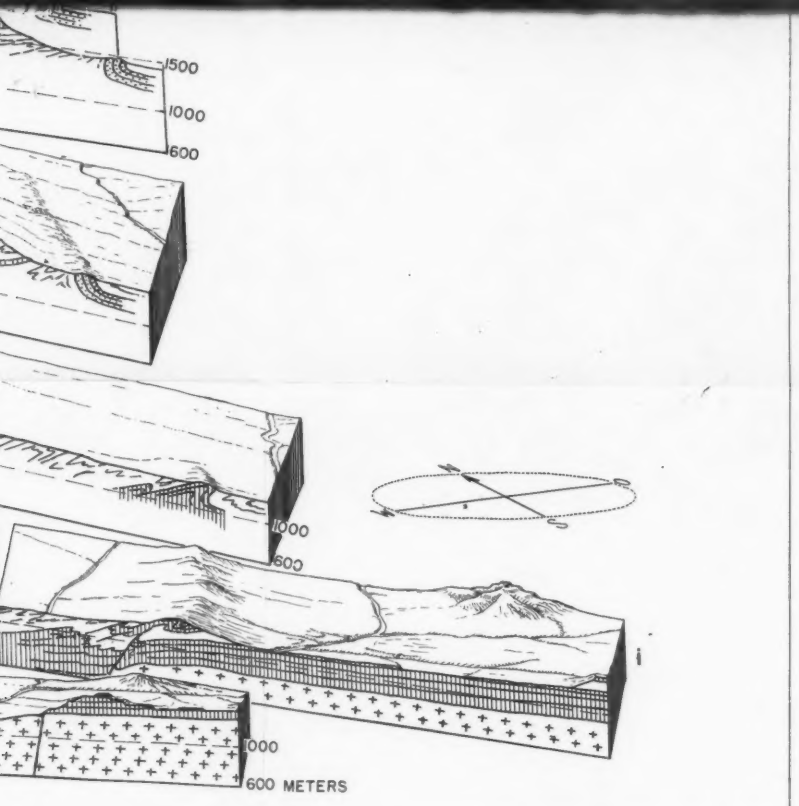


B. NORTHWEST-SOUTHEAST SECTIONS T

1, Pre-Nama basement; 2, Schwarzkalk series, 2a, Schwarzrand series (shales and quartzite); 3, Unconformity dolomite; 4, Zebra series; 5, Pavian series (southern facies); 5a, Pavian series (northern facies); 6, Dassie series; 7, Kudu series. The folded sedimentary rocks ment. Basement rocks have been little dis intensely folded sedimentary rocks. The U

COMPOSITE SE



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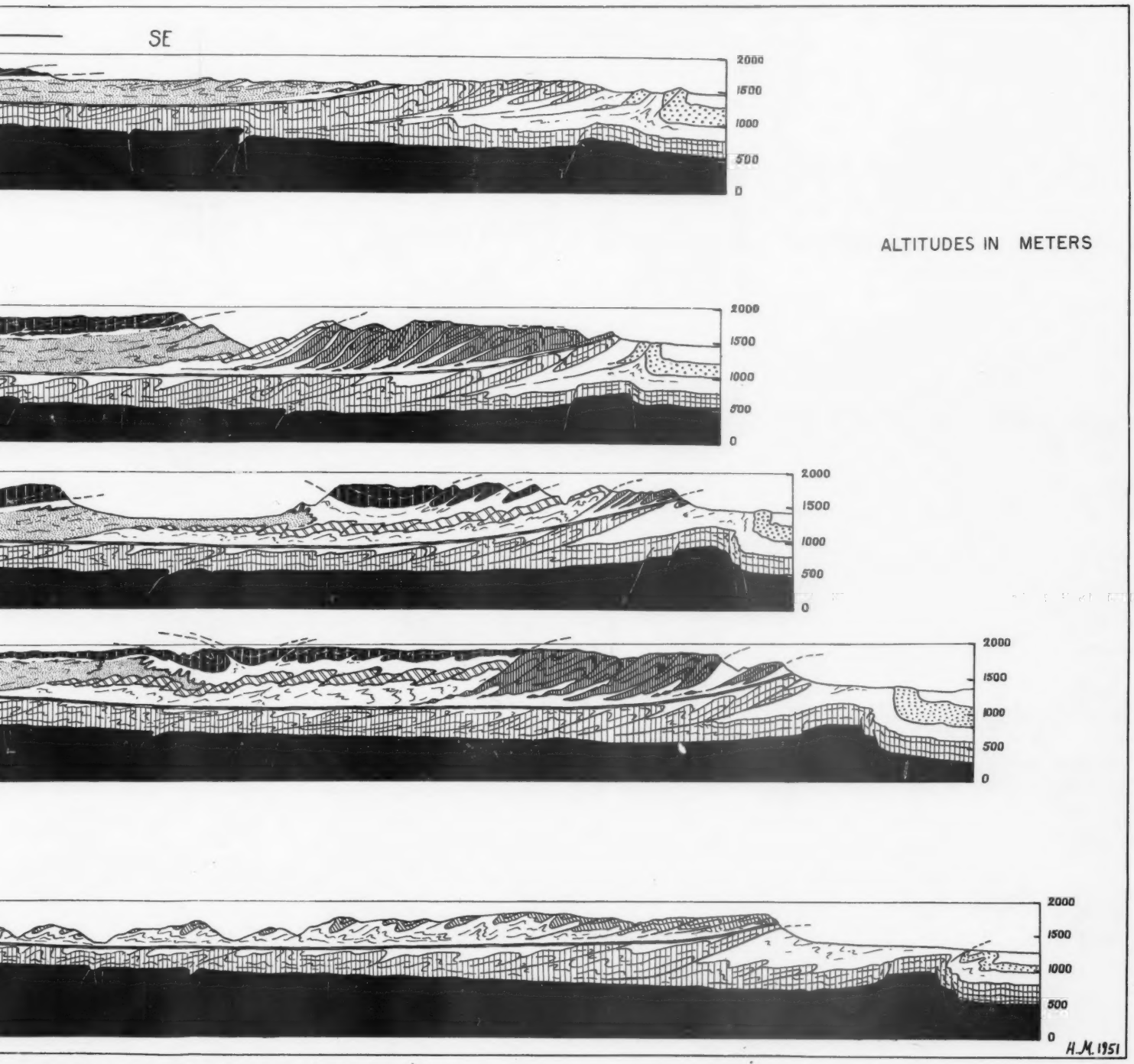
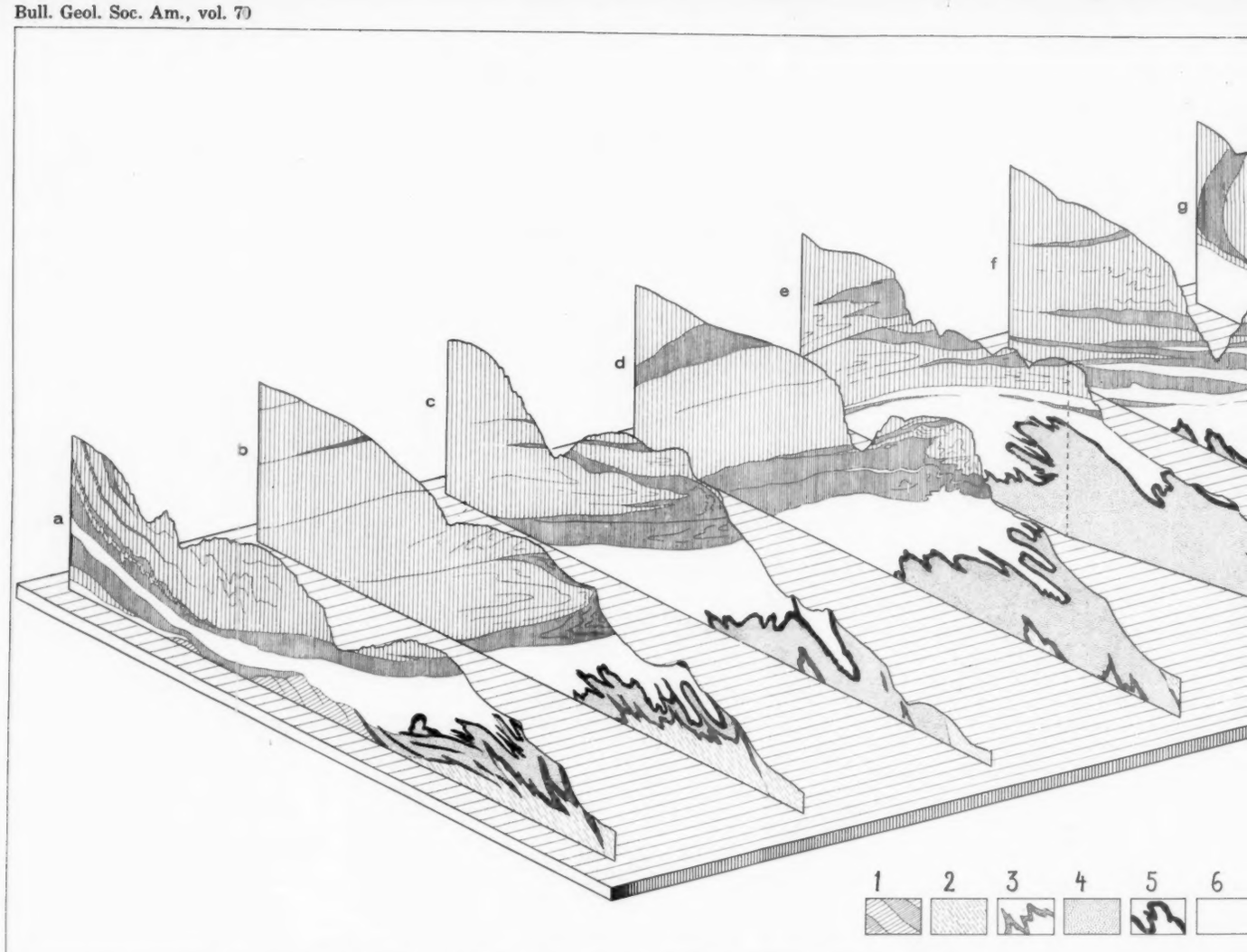


S THROUGH NAUKLUFT MOUNTAINS

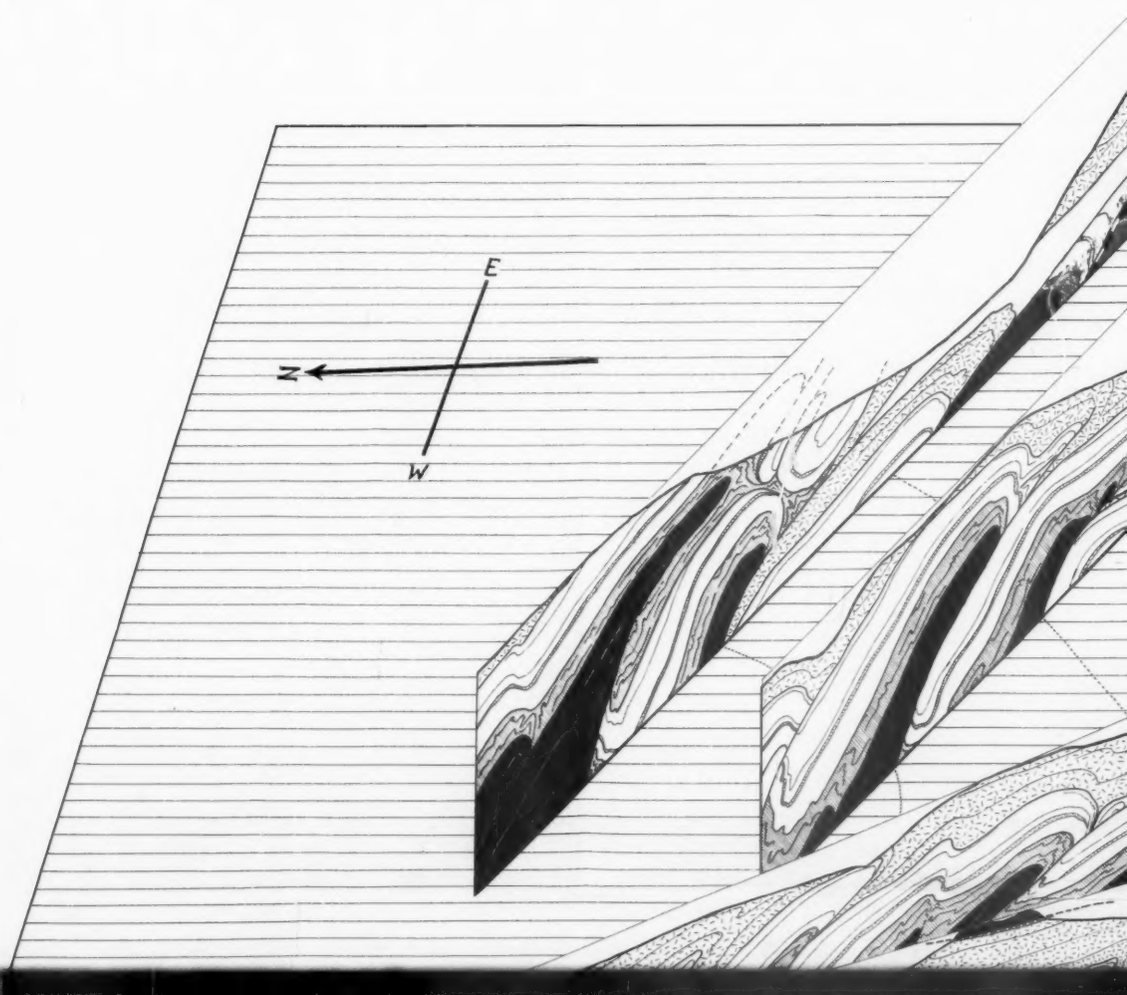
rocks fill a basin formed by the base-
le disturbed in comparison with the
The Unconformity dolomite (3) sepa-
rates an older and younger phase of folding without being itself deformed. This dolomite is, in different areas, overlain by not fewer than four formations (4, 5, 5a, and 6).

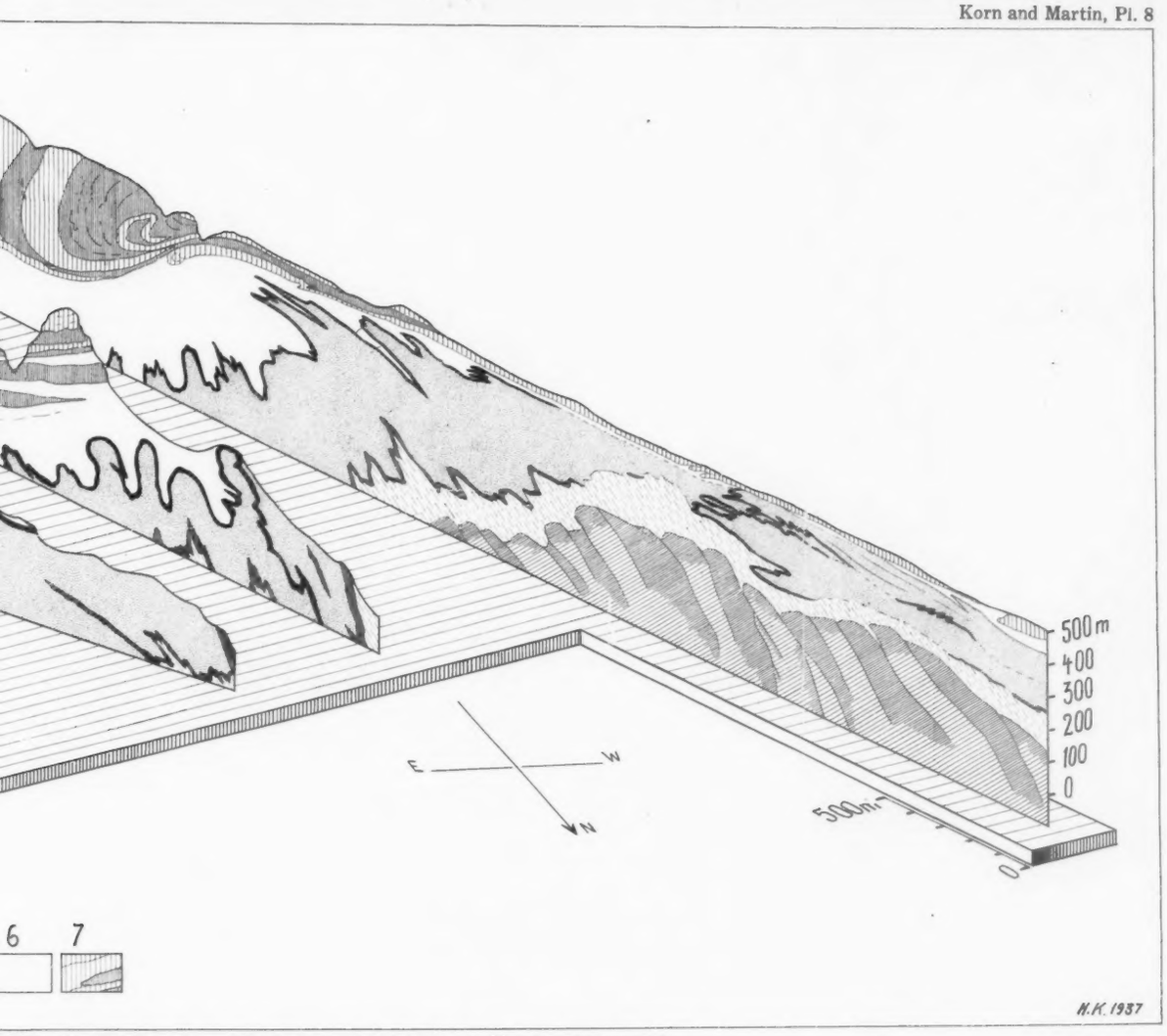
SECTIONS



A. PROFILES OF SOUTHERN AND SOUTHWESTERN

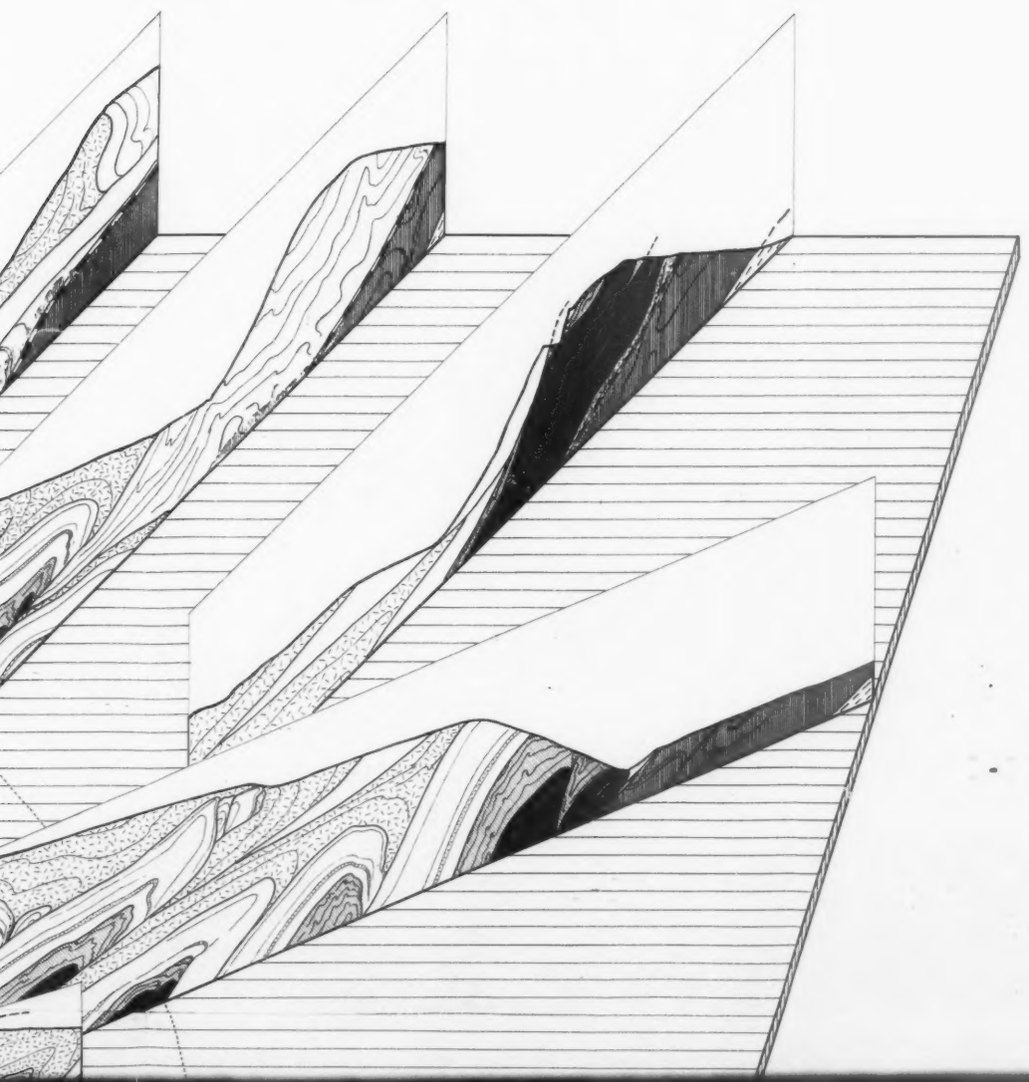
1, Dolomite of southern facies of Pavian series; 2–5, Pavian series, northern facies (2, brown arenaceous slates; 3, blue conglomeratic limestone; 4, boulder sla
laminated





RN MOUNTAIN FACE, FARM BLÄSSKRANZ

er slates; 5, white dolomite); 6–7, Kudu series (6, purple slates and ated limestone; 7, platy and massive dolomites).



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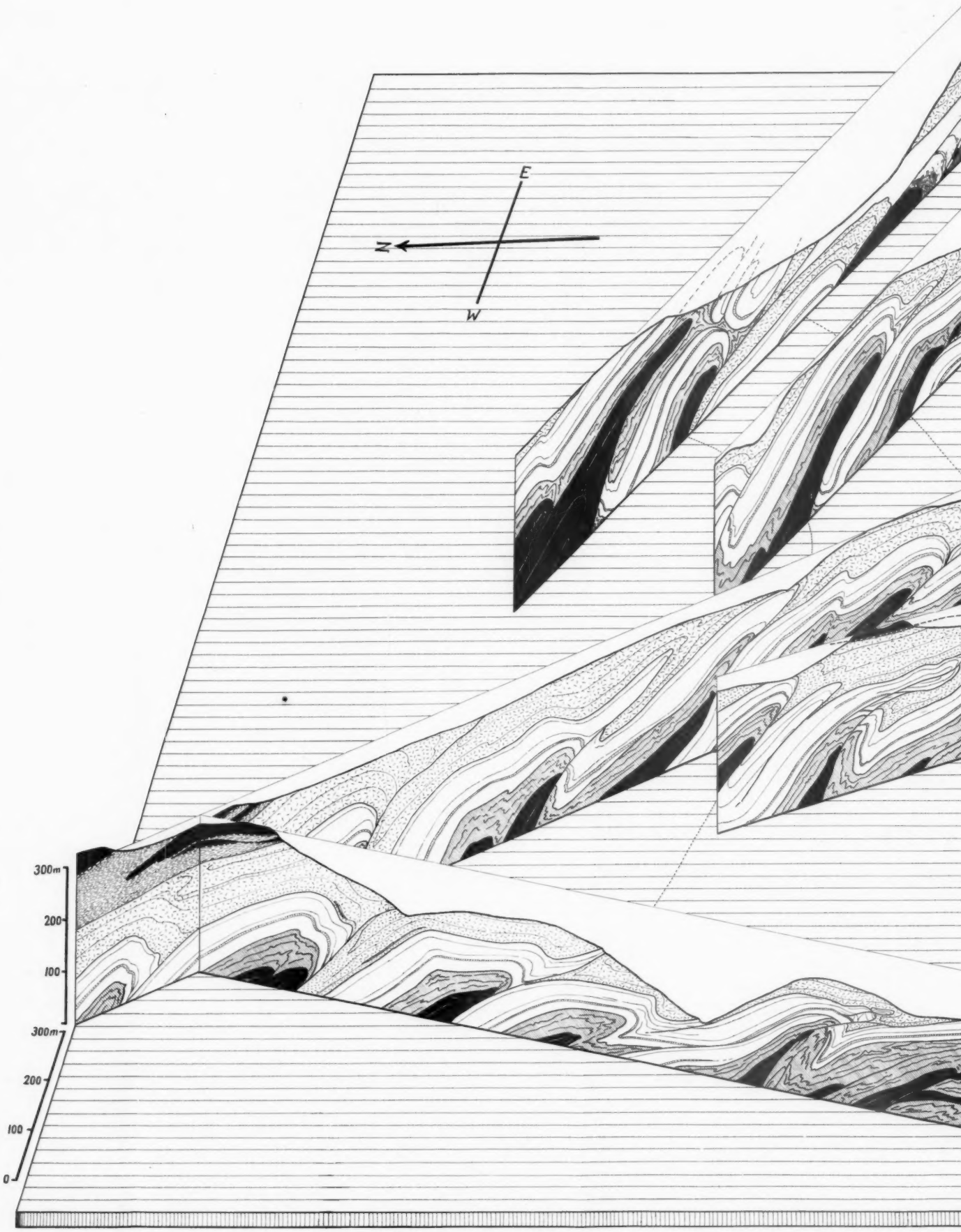


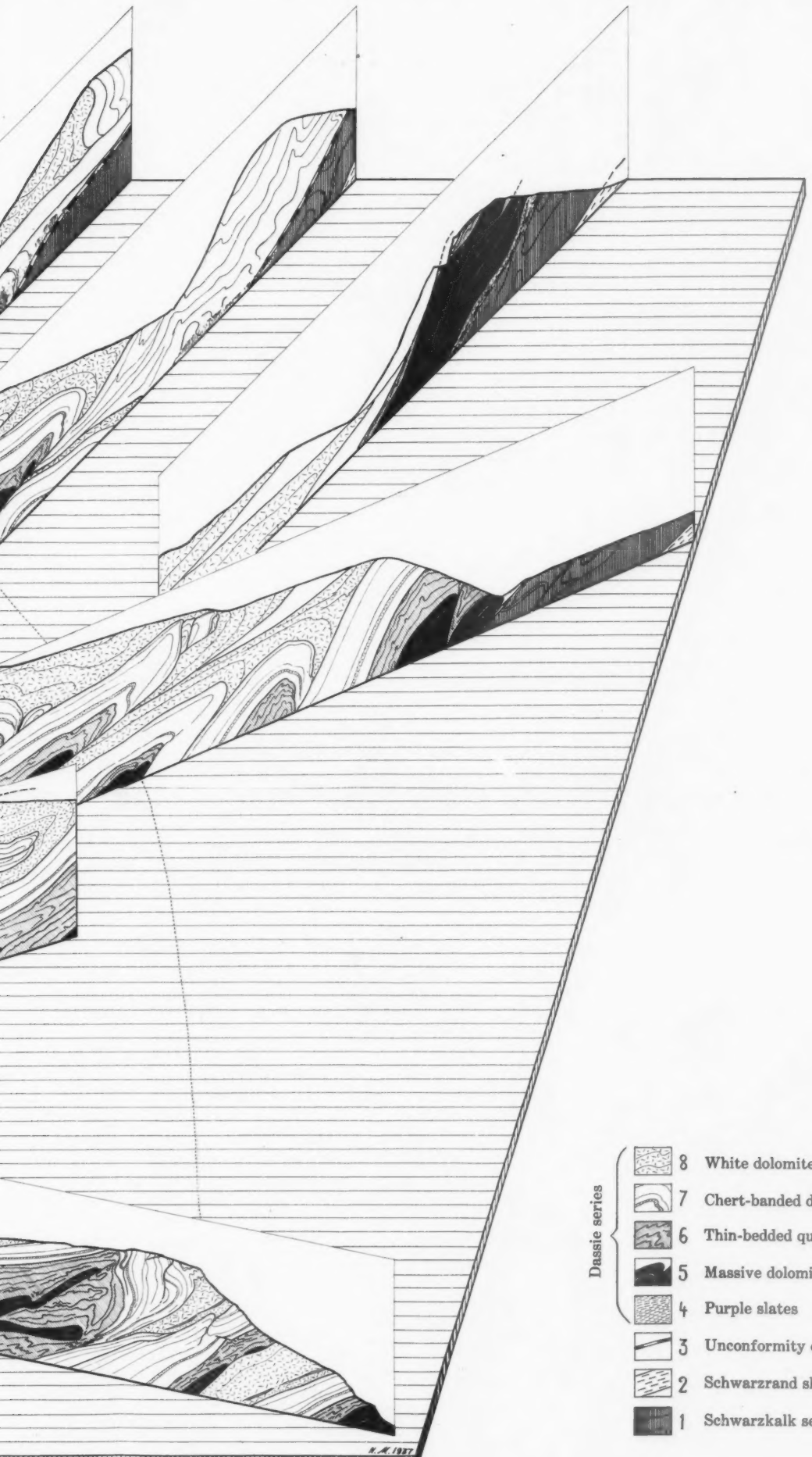
B. SECTIONS THROUGH FRONT RANGE, FARM BÜLL

The Dassie nappe (its base on the Unconformity dolomite is shown only in the upper profiles) consists of imbricated digitations. Curving thrust planes and formation of digitations result from differential retardation by friction.

Dashed lines on the datum plane connect indivi the arcuate pattern of the whole structure. A basal bluish-purple slates (4) and lowest dolomit

RN MOUNTAIN FACE, FARM BLÄSSKRANZ

der slates; 5, white dolomite); 6–7, Kudu series (6, purple slates and nated limestone; 7, platy and massive dolomites).



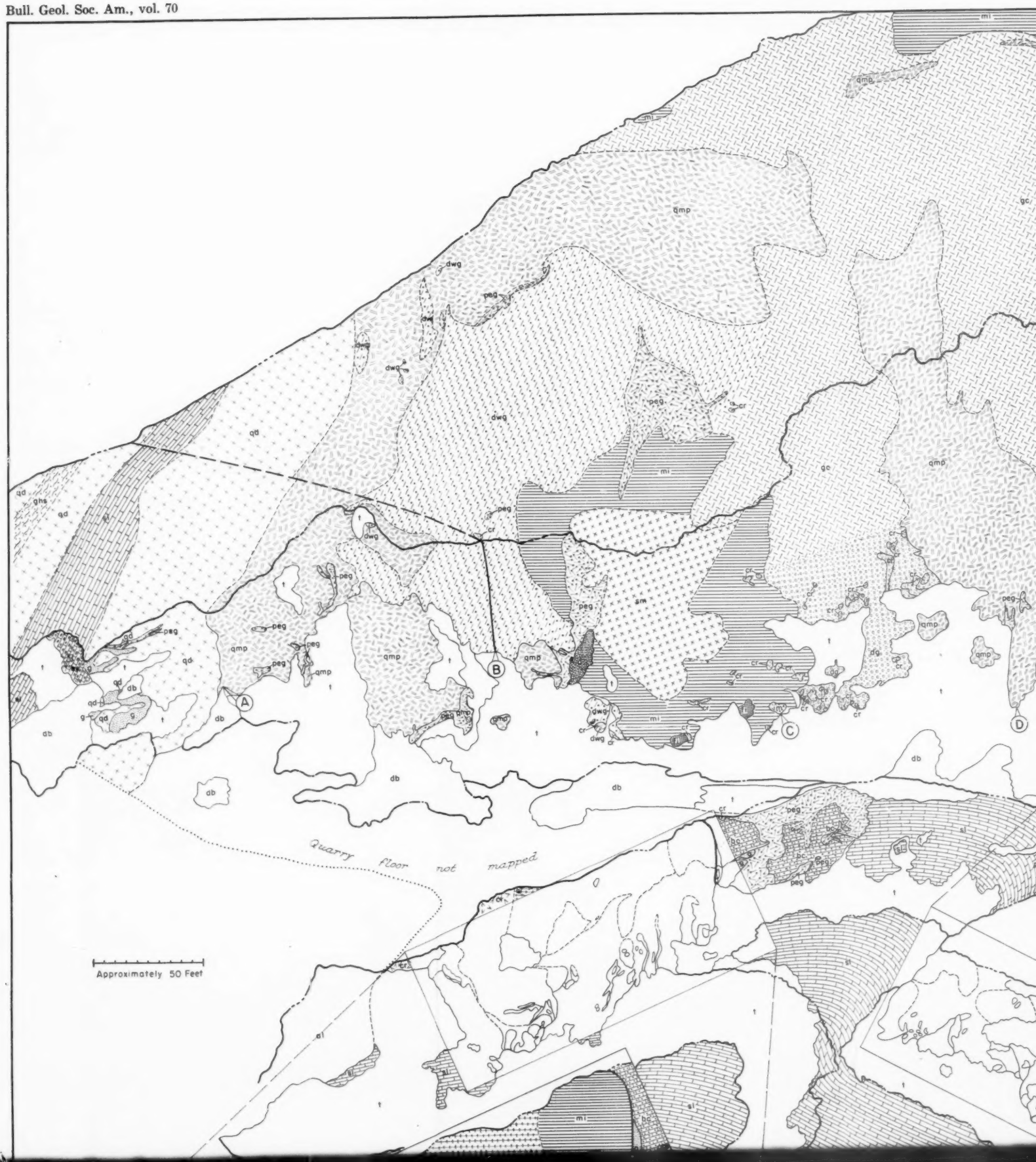
Dassie series

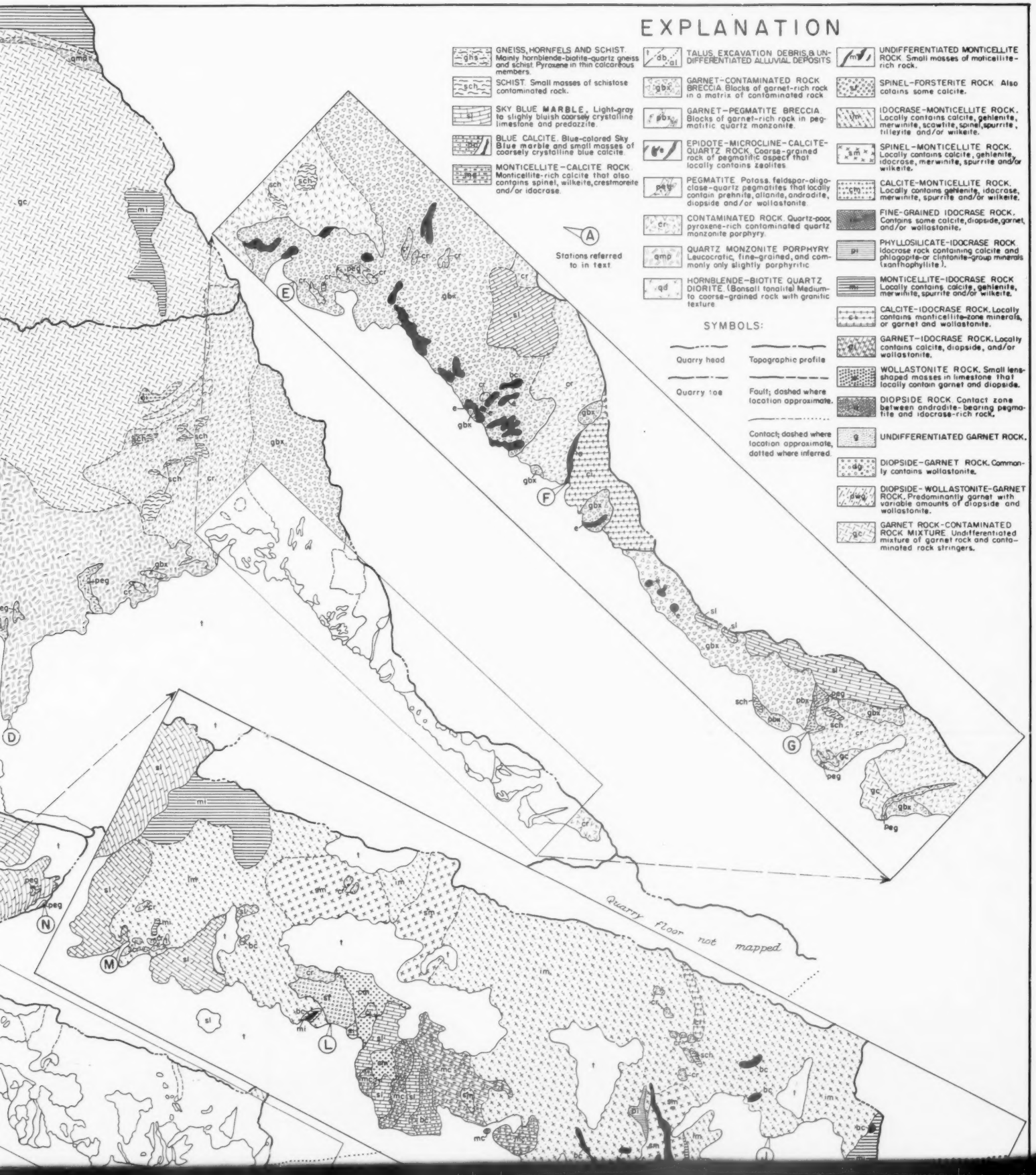
- 8 White dolomite
- 7 Chert-banded dolomite
- 6 Thin-bedded quartzites and purple slates
- 5 Massive dolomite and red limestone
- 4 Purple slates
- 3 Unconformity dolomite
- 2 Schwarzrand shales
- 1 Schwarzkalk series

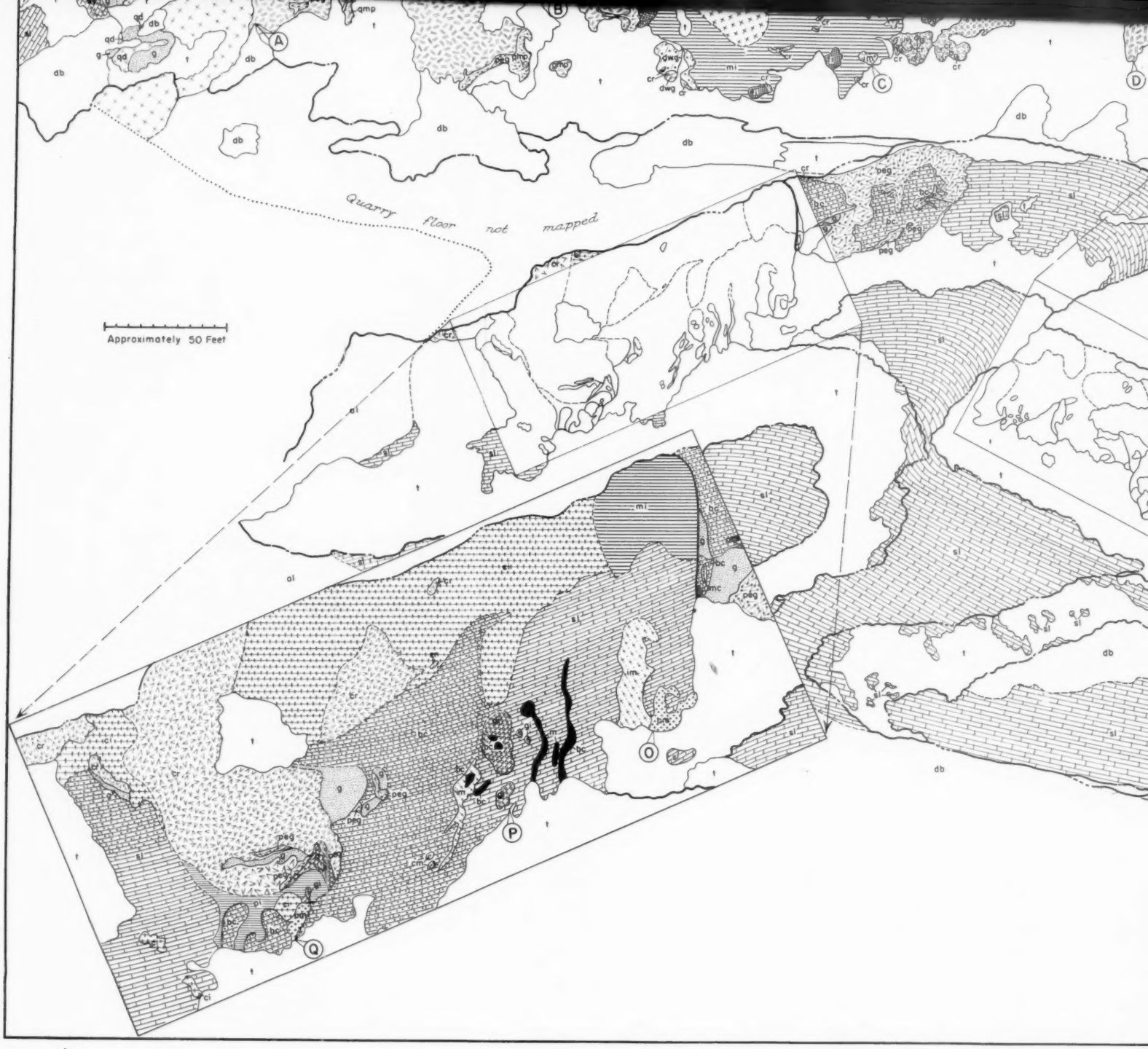
ÜLLSPORT, NORTHEAST OF TSONDAB RIVER

ndividual fold elements and show re. A second, higher nappe with lomite (5) appears at the extreme north end of the lowest section and as a small outlier on top of the small profile in the center.

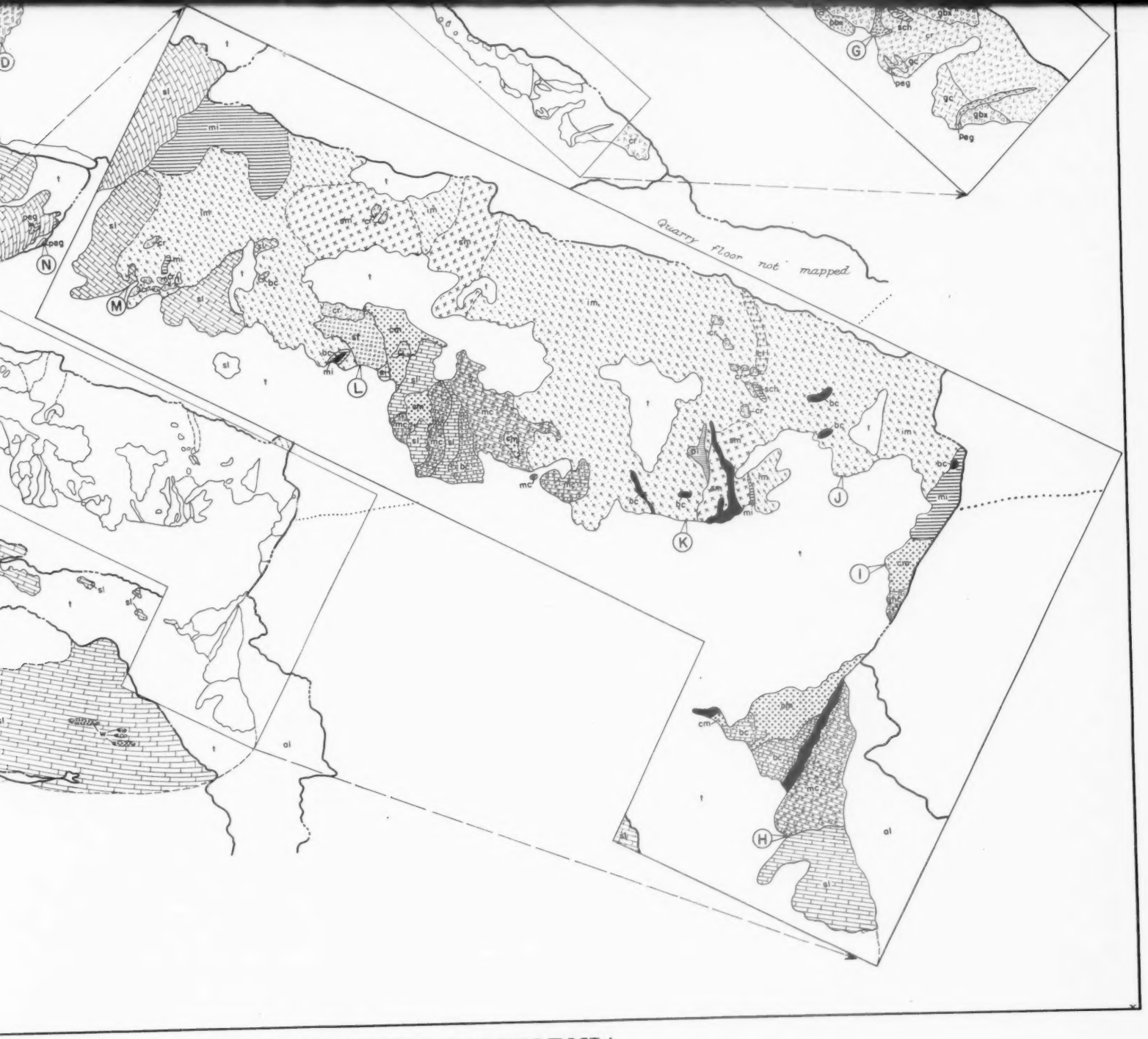
RANZ AND BÜLLSPORT


Quarry floor not mapped
Approximately 50 Feet
A
B
C
D
qmp
mi
dwg
peg
qd
ghs
db
gc
sm
dg
cr
sl
bc
t

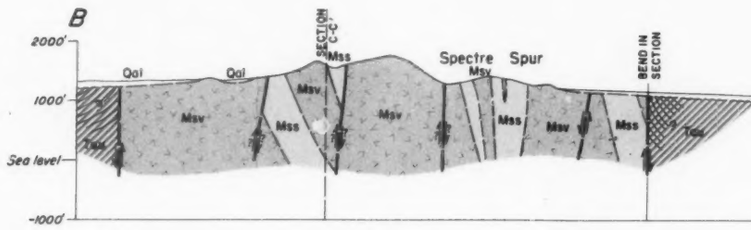

EXPLANATION
GNEISS, HORNFELS AND SCHIST. Mainly hornblende-biotite-quartz gneiss and schist. Pyroxene in thin calcareous members.
SCHIST. Small masses of schistose contaminated rock.
SKY BLUE MARBLE. Light-gray to slightly bluish coarsely crystalline limestone and predazzite.
BLUE CALCITE. Blue-colored Sky Blue marble and small masses of coarsely crystalline blue calcite.
MONTICELLITE–CALCITE ROCK. Monticellite-rich calcite that also contains spinel, wilkeite, crestmoreite and/or idocrase.
TALUS, EXCAVATION DEBRIS & UNDIFFERENTIATED ALLUVIAL DEPOSITS
GARNET–CONTAMINATED ROCK BRECCIA. Blocks of garnet-rich rock in a matrix of contaminated rock
GARNET–PEGMATITE BRECCIA. Blocks of garnet-rich rock in pegmatitic quartz monzonite.
EPIDOTE–MICROCLINE–CALCITE–QUARTZ ROCK. Coarse-grained rock of pegmatitic aspect that locally contains zeolites.
PEGMATITE. Potass. feldspar-oligoclase-quartz pegmatites that locally contain prehnite, allanite, andradite, diopside and/or wollastonite.
CONTAMINATED ROCK. Quartz-poor, pyroxene-rich contaminated quartz monzonite porphyry.
QUARTZ MONZONITE PORPHYRY. Leucocratic, fine-grained, and commonly only slightly porphyritic
HORNBLENDE–BIOTITE QUARTZ DIORITE. (Bonsall tonalite) Medium- to coarse-grained rock with granitic texture
A
Stations referred to in text
SYMBOLS:
Quarry head
Topographic profile
Quarry toe
Fault; dashed where location approximate.
Contact; dashed where location approximate, dotted where inferred.
UNDIFFERENTIATED MONTICELLITE ROCK. Small masses of monticellite-rich rock.
SPINEL–FORSTERITE ROCK. Also colains some calcite.
IDOCRASE–MONTICELLITE ROCK. Locally contains calcite, gehlenite, merwinite, scawtite, spinel, spurrite, tilleyite and/or wilkeite.
SPINEL–MONTICELLITE ROCK. Locally contains calcite, gehlenite, idocrase, merwinite, spurrite and/or wilkeite.
CALCITE–MONTICELLITE ROCK. Locally contains gehlenite, idocrase, merwinite, spurrite and/or wilkeite.
FINE-GRAINED IDOCRASE ROCK. Contains some calcite, diopside, garnet, and/or wollastonite.
PHYLLOSILICATE–IDOCRASE ROCK. Idocrase rock containing calcite and phlogopite-or clintonite-group minerals (xanthophyllite).
MONTICELLITE–IDOCRASE ROCK. Locally contains calcite, gehlenite, merwinite, spurrite and/or wilkeite.
CALCITE–IDOCRASE ROCK. Locally contains monticellite-zone minerals, or garnet and wollastonite.
GARNET–IDOCRASE ROCK. Locally contains calcite, diopside, and/or wollastonite.
WOLLASTONITE ROCK. Small lens-shaped masses in limestone that locally contain garnet and diopside.
DIOPSIDE ROCK. Contact zone between andradite-bearing pegmatite and idocrase-rich rock.
UNDIFFERENTIATED GARNET ROCK.
DIOPSIDE–GARNET ROCK. Commonly contains wollastonite.
DIOPSIDE–WOLLASTONITE–GARNET ROCK. Predominantly garnet with variable amounts of diopside and wollastonite.
GARNET ROCK–CONTAMINATED ROCK MIXTURE. Undifferentiated mixture of garnet rock and contaminated rock stringers.
Quarry floor not mapped.

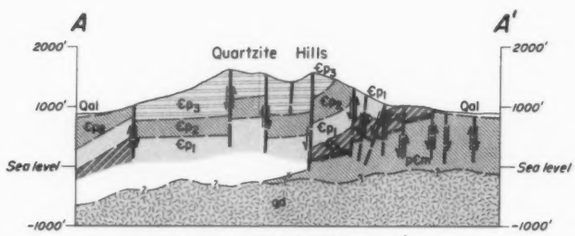


GEOLOGIC MAP OF FACES OF THE COMMER

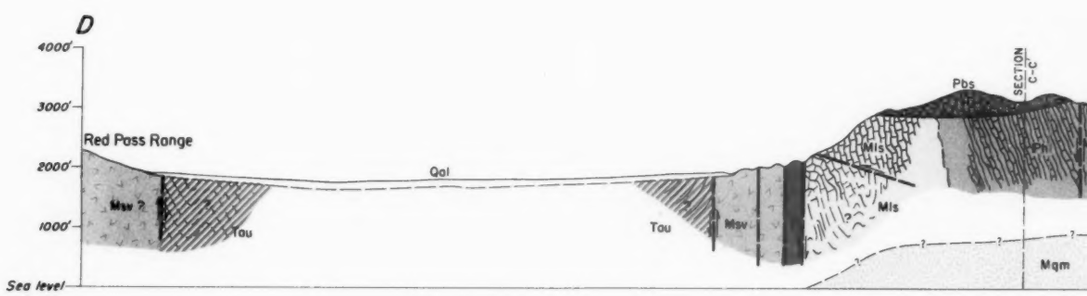


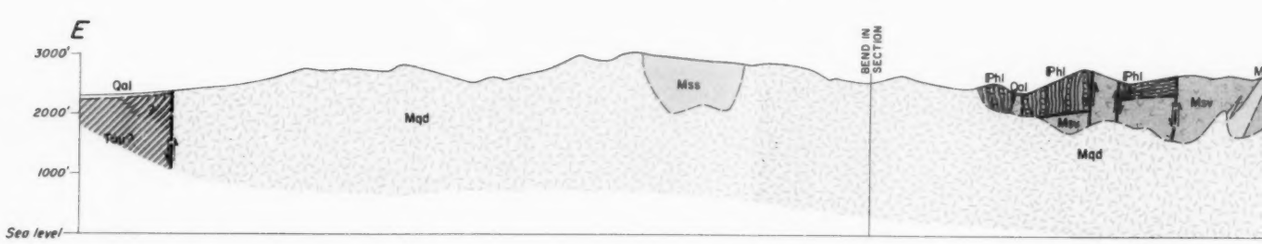
IERCIAL QUARRY, CRESTMORE, CALIFORNIA

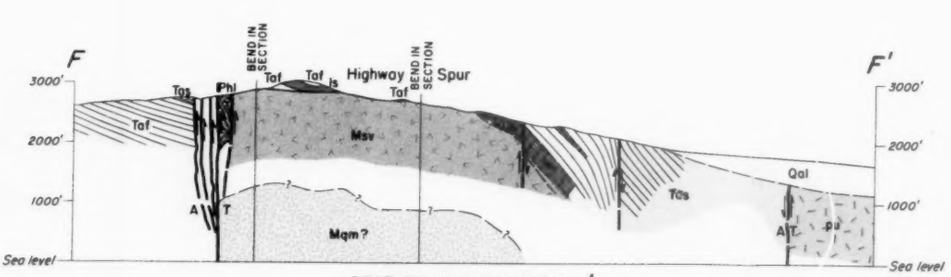




SECTION ALONG LINE A-A'







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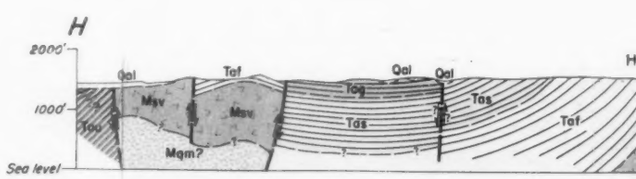
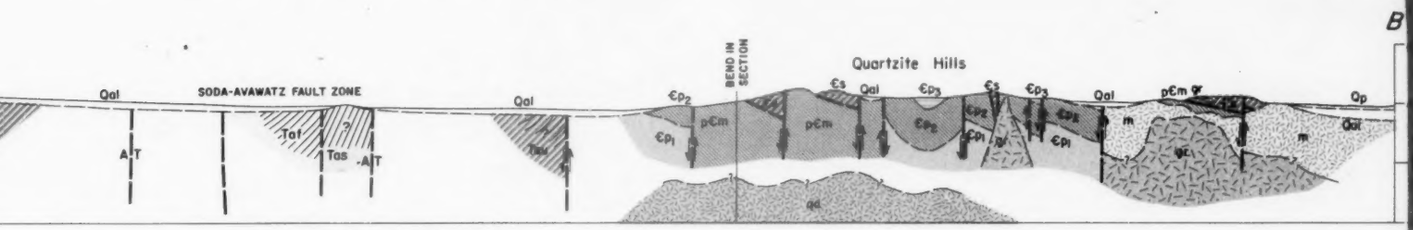
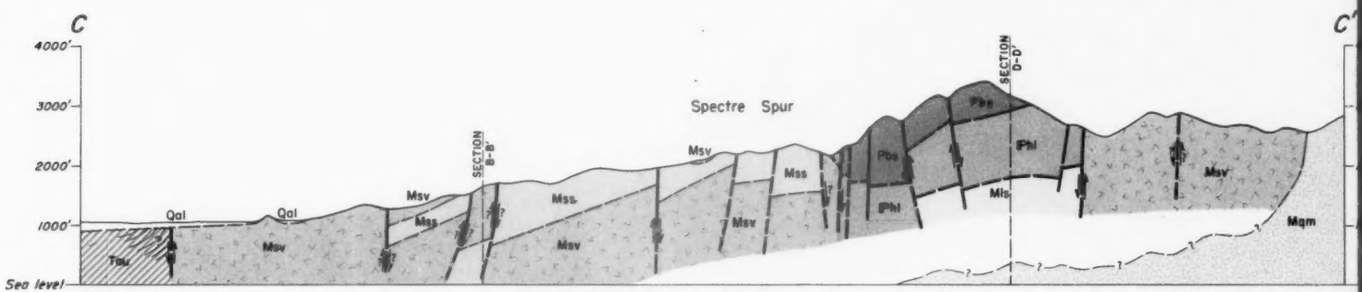


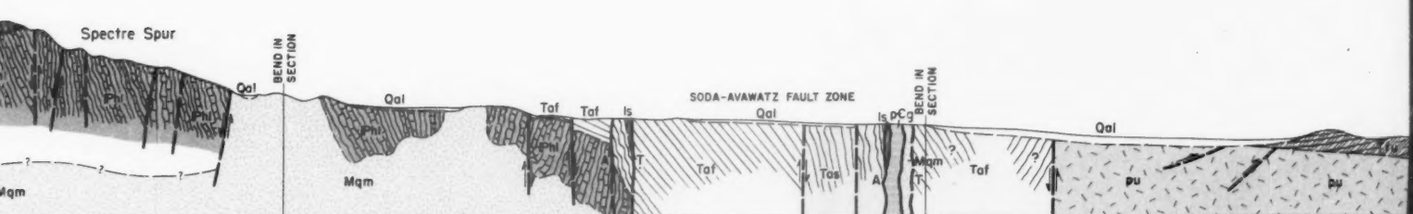
STRUCTURAL CROSS SECTIONS THROUGH THE N



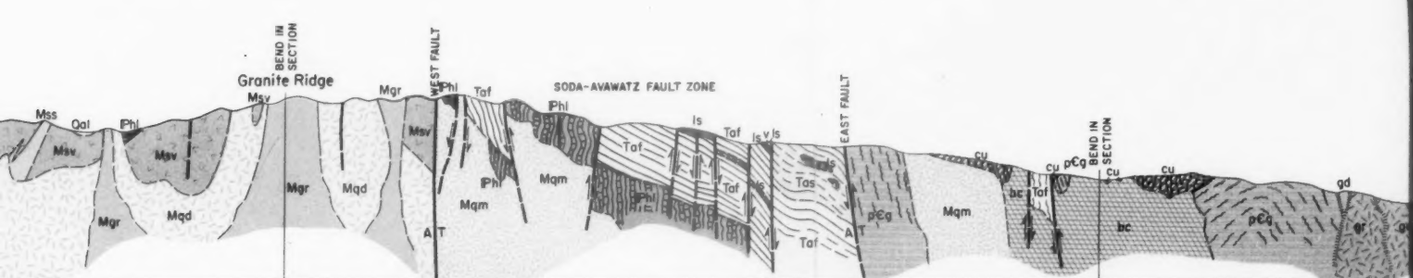
SECTION ALONG LINE B-B′



SECTION ALONG LINE C-C′



SECTION ALONG LINE D-D′



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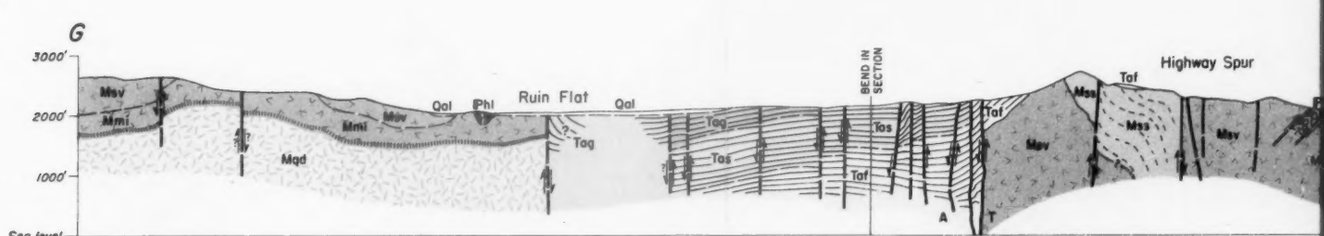
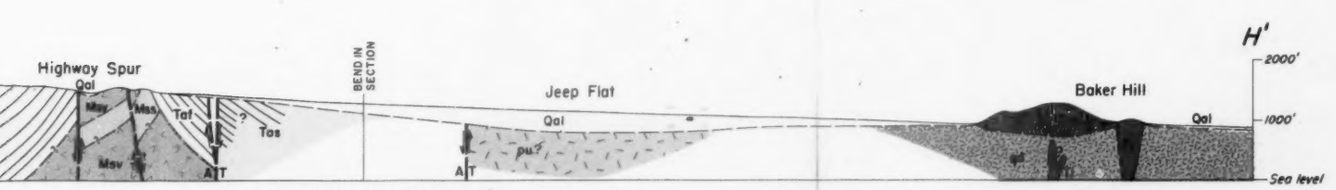


SECTION ALONG LINE G-G′

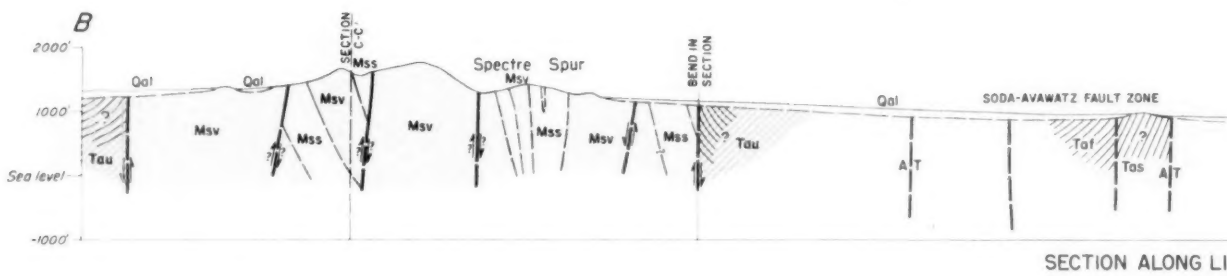


SECTION ALONG LINE H-H′

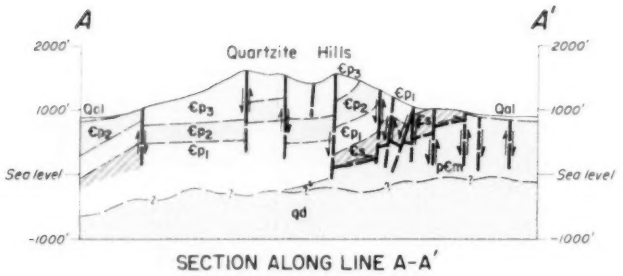
Horizontal and vertical scale 1:31 680

1 1/2 0 1 Mile

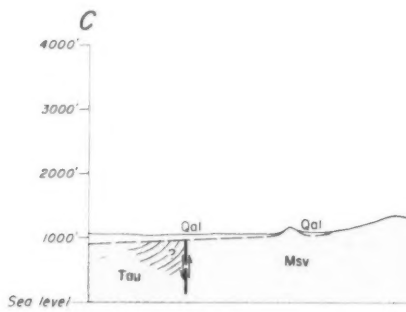
E NORTHEAST PART OF THE SODA MOUNTAINS, SAN BERNARDINO COUNTY, CA

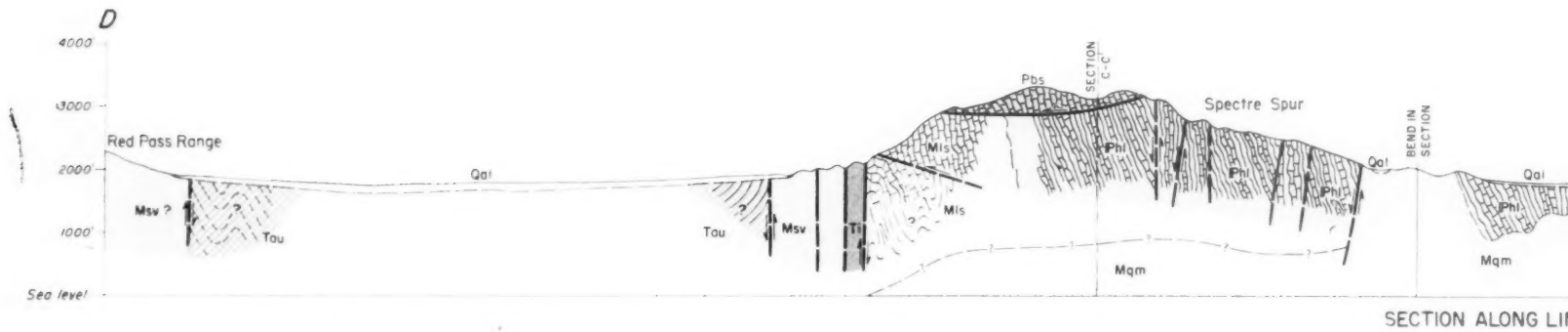


SECTION ALONG LI

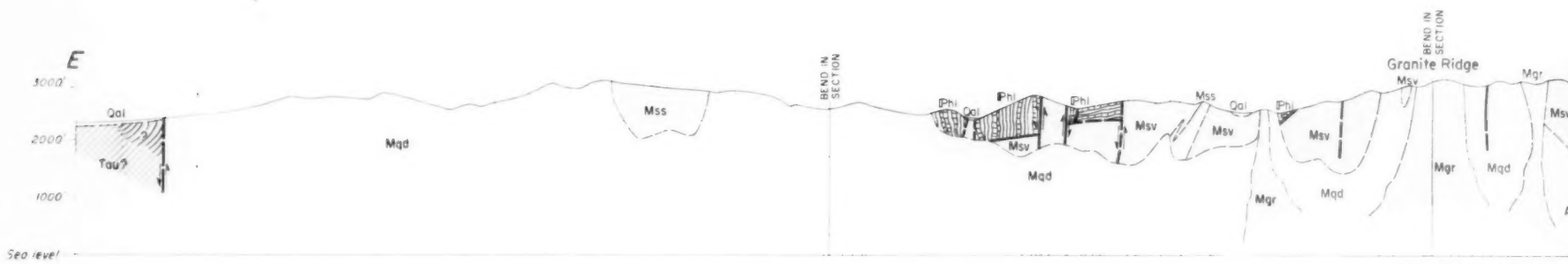


SECTION ALONG LINE A-A'

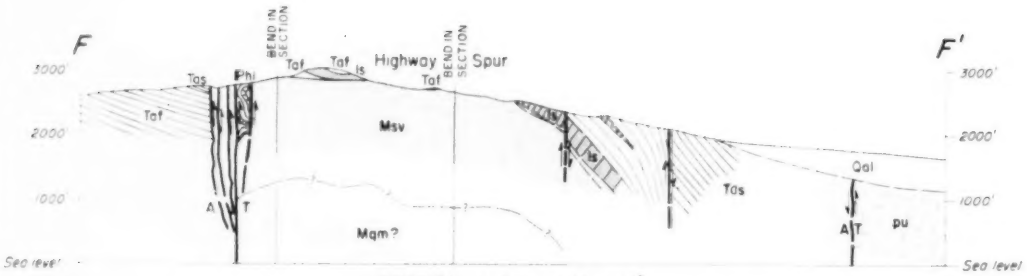




SECTION ALONG LI



SECTION ALONG LI



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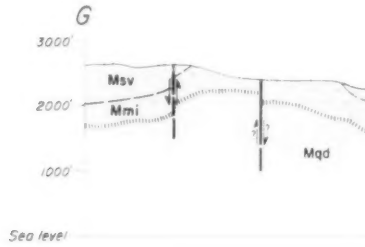

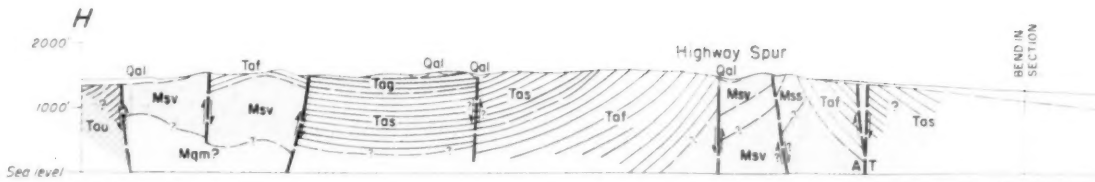

SECTION ALONG LIN

Horizontal and vertical sca

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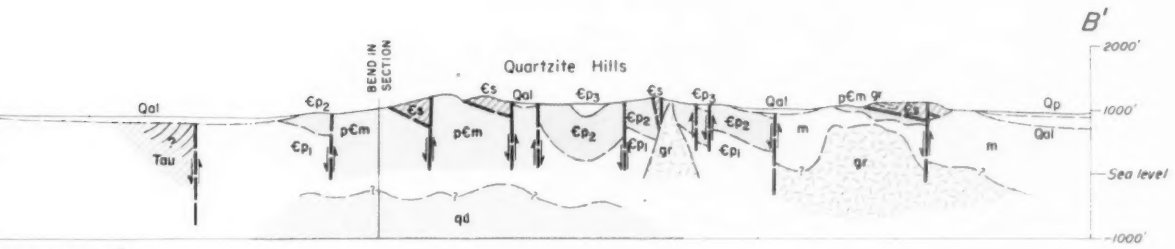
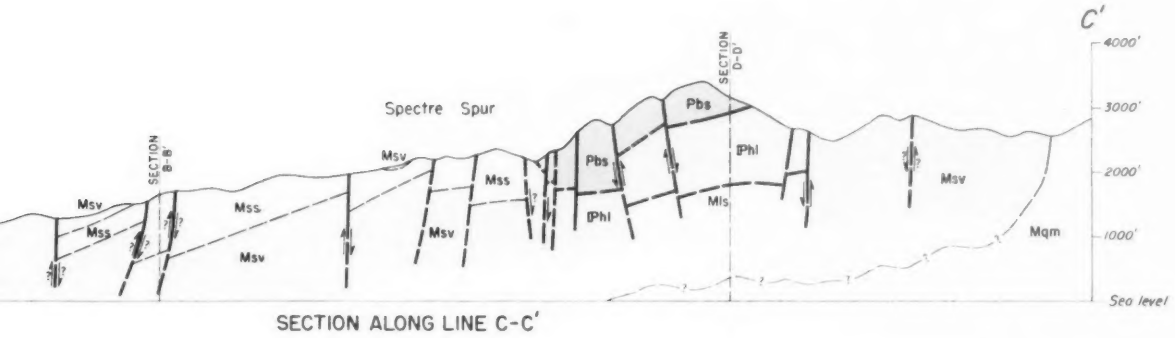
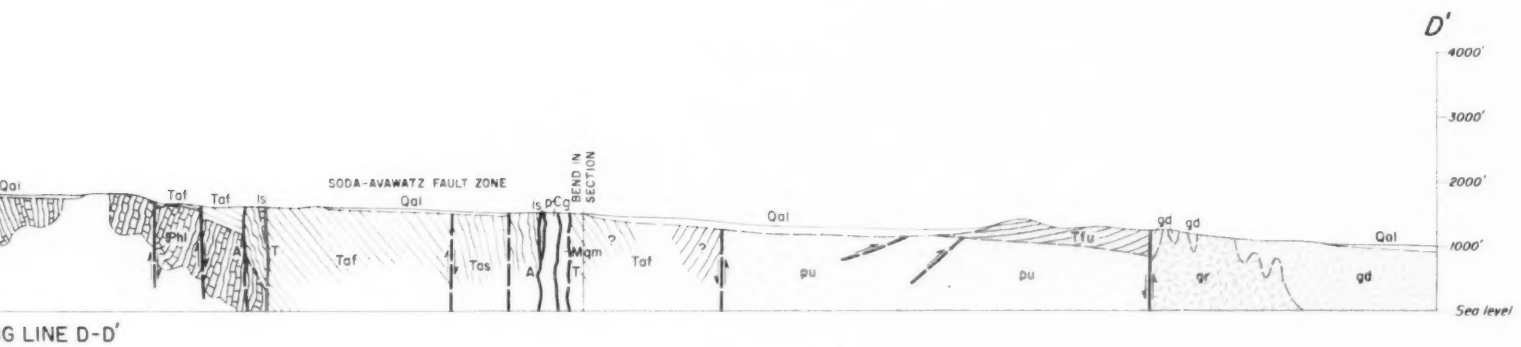
STRUCTURAL CROSS SECTIONS THROUGH THE NORTHEAST PART OF



G LINE B-B'



SECTION ALONG LINE C-C'



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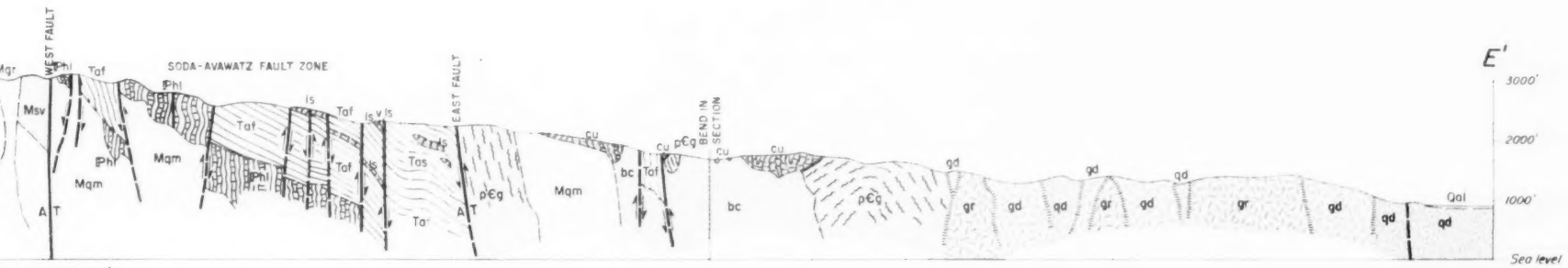
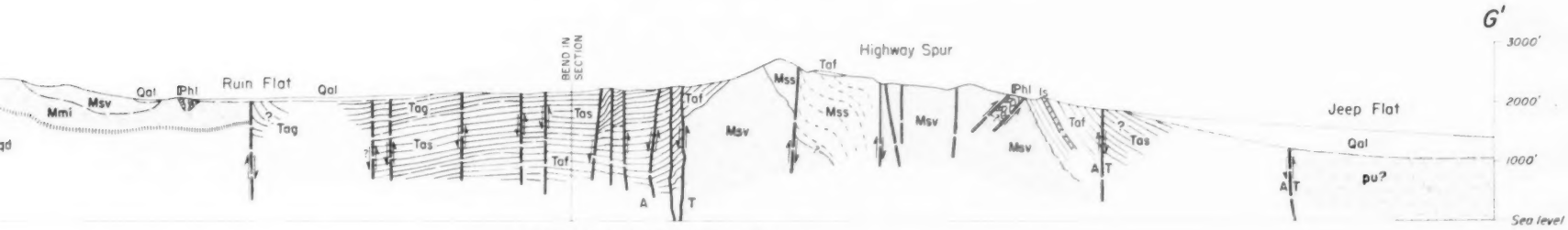


G LINE E-E'



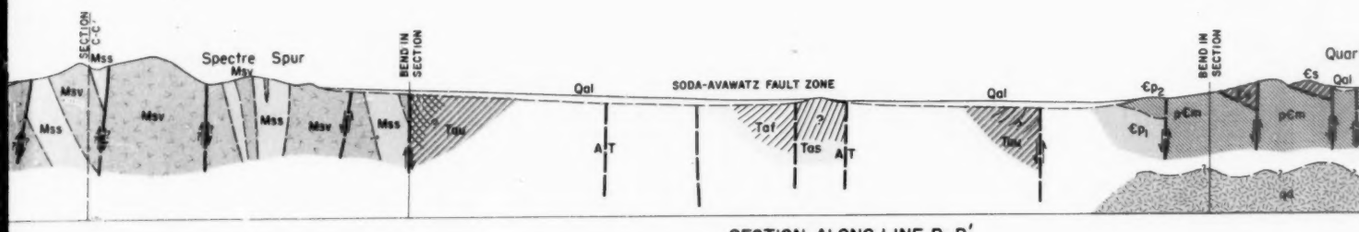
SECTION ALONG LINE G-G'

G LINE H-H'

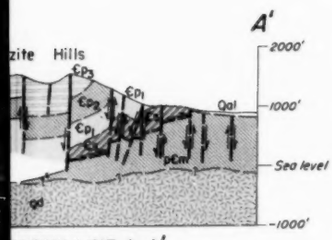
l scale 1 31 680

1 Mile

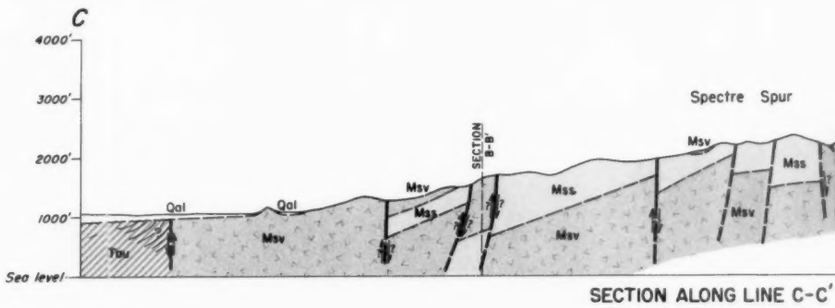
OF THE SODA MOUNTAINS, SAN BERNARDINO COUNTY, CALIFORNIA



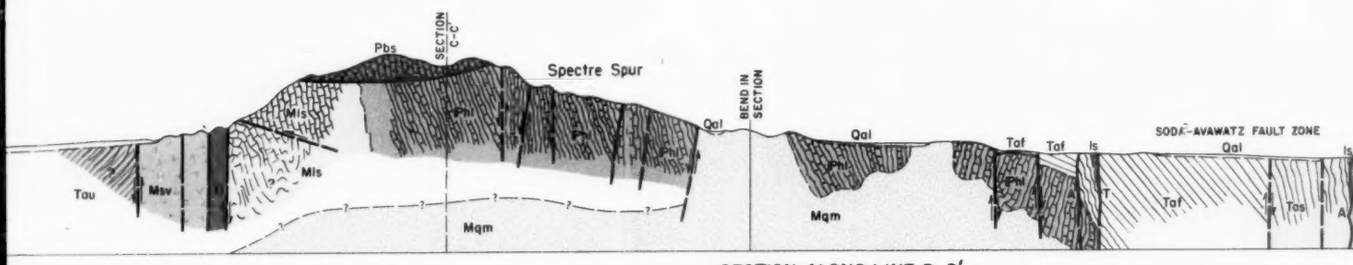
SECTION ALONG LINE B-B'



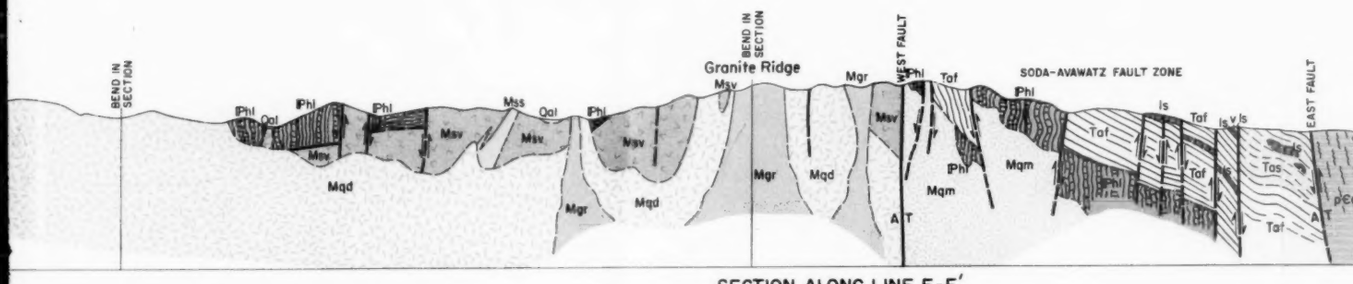
ALONG LINE A-A'



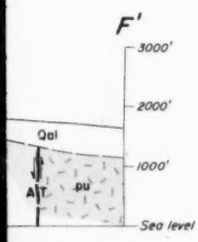
SECTION ALONG LINE C-C'

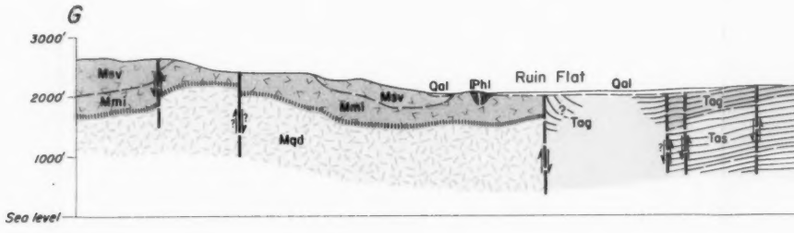


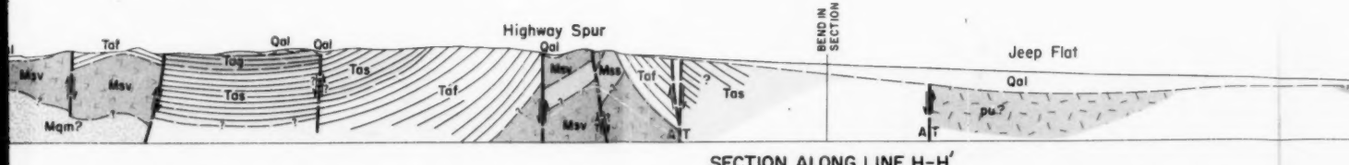
SECTION ALONG LINE D-D'



SECTION ALONG LINE E-E'





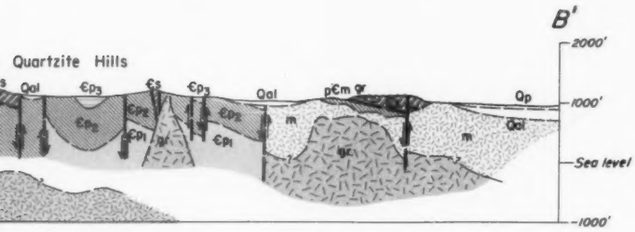


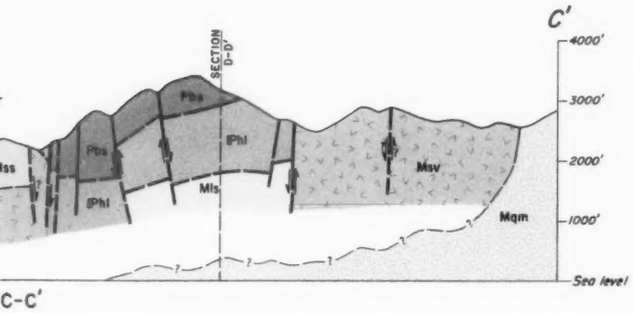
SECTION ALONG LINE H-H'

Horizontal and vertical scale 1:31 680

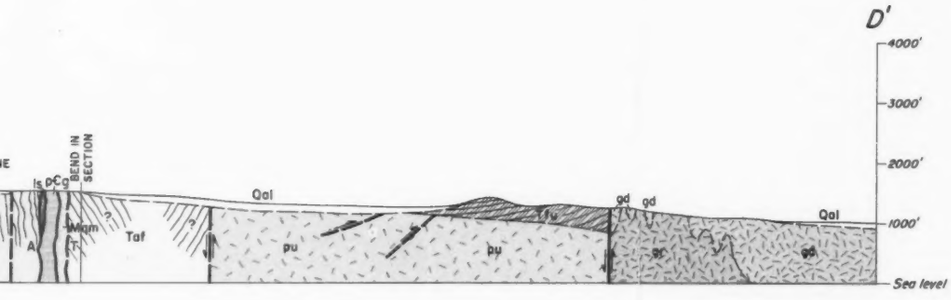
1 1/2 0 1 Mile

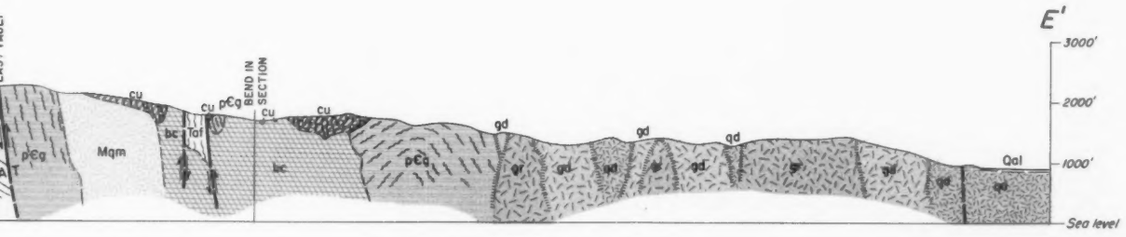
S SECTIONS THROUGH THE NORTHEAST PART OF THE SODA MOUNTAINS, SA

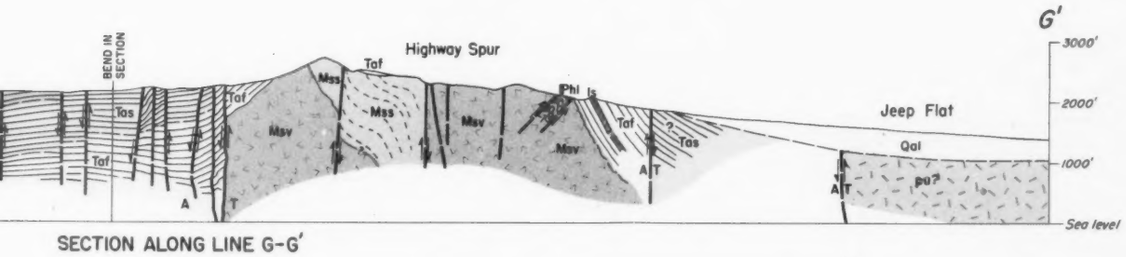




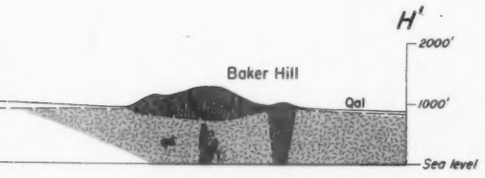
C-C'







SECTION ALONG LINE G-G'



SAN BERNARDINO COUNTY, CALIFORNIA